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Stormwater Management Plan Review Course

Virginia Department of Environmental Quality

Module 7:
Best Management Practices

Non-Structural Best Management Practices

- Direct growth to identified areas;
- Protect sensitive aquatic resources;
- Establish buffers along stream and other waters;
- Maintain existing runoff patterns and Tc;
- Minimize impervious surfaces;
- Minimize disturbance of soils and vegetation;
- Encourage infill and re-development;
- Educate on material disposal/recycling
- Spill Prevention/Clean Up
- Identify and eliminate illicit discharges
- Promote street sweeping
- Develop Public Education/Participation programs

Non-Proprietary Clearinghouse BMPs

1. **Impervious Disconnection**
2. **Sheet flow to Conservation Area/Filter Strip**
3. **Grass Channels**
4. **Soils Compost Amendments**
5. Vegetated Roofs
6. Rainwater Harvesting
7. Permeable Pavement
8. Infiltration
9. Bioretention (including Urban Bioretention)
10. Dry Swales
11. Wet Swales
12. Filtering Practices
13. Constructed Wetlands
14. Wet Ponds
15. Dry Extended Detention Ponds

Site Design BMPs

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BMP Design Specifications

- All BMP Design Specifications can be found at:

  http://www.vwrrc.vt.edu/swc/NonProprietaryBMPs.html

2011 version referenced in regulations with minor corrections (no one would want 48 feet maximum soil depth for Bioretention!) and updates

- No changes made to performance credits or critical sizing methods

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BMP Design Specifications

- Changes in design tables reflecting spreadsheet logic:
  - √ Definition of design treatment volume as: **"Tv_{BMP} = [(1)(Rv)(A) / 12] + any remaining volume from upstream BMP(s)" in treatment train**;
  - x Rather than "Tv_{BMP} = [(1)(Rv)(A) / 12] –volume reduced by upstream BMP(s)"
- Changes to improve graphics, clarification in response to questions and comments
- General review and fix of inconsistencies

Rooftop/Impervious Area Disconnection

VIRGINIA DEQ STORMWATER DESIGN SPECIFICATION No. 1

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Rooftop/Impervious Area Disconnection

VIRGINIA DEQ STORMWATER DESIGN SPECIFICATION No. 1

Summary of Stormwater Functions [1]

FUNCTION PROVIDED BY SIMPLE ROOFTOP DISCONNECTION	HSG SOILS A and B	HSG SOILS C and D
Annual Runoff Volume Reduction (RR)	50%	25%
Total Phosphorus (TP) EMC Reduction by BMP Treatment Process	0	0
Total Phosphorus (TP) Mass Load Removal	50%	25%
Total Nitrogen (TN) EMC Reduction by BMP Treatment Process	0	0
Total Nitrogen (TN) Mass Load Removal	50%	25%
Channel & Flood Protection	**Partial:** Designers can use the VRRM Compliance spreadsheet to adjust curve number for each design storm for the contributing drainage area (CDA), based on annual runoff reduction achieved	

NOTE: Stormwater functions of disconnection can be boosted if an acceptable alternate runoff reduction practice is employed. Acceptable practices and their associated runoff reduction rates are listed below. Designers should consult the applicable specification number for design standards.

Alternate Practice	Specification No.	Runoff Reduction Rate
Soil compost-amended filter path	4	50%[2]
Dry well or french drain #1 (Micro-infiltration #1)	8	50%
Dry well or french drain #2 (Micro-infiltration #2)	8	90%
Rain garden #1, front yard bioretention (Micro-bioretention #1)	9	40%
Rain garden #2, front yard bioretention (Micro-bioretention #2)	9	80%
Rainwater harvesting	6	Defined by user
Stormwater Planter (Urban Bioretention)	9 (Appendix A)	40%

[1] CWP and CSN (2008), CWP (2007)

[2] Compost amendments are not credited with additional volume reduction an HSG A & B soils. Primary use is to improve the volume reduction performance of disconnection in C & D soils.

Rooftop/Impervious Area Disconnection

VIRGINIA DEQ STORMWATER DESIGN SPECIFICATION No. 1

Simple Rooftop Disconnection Design Criteria

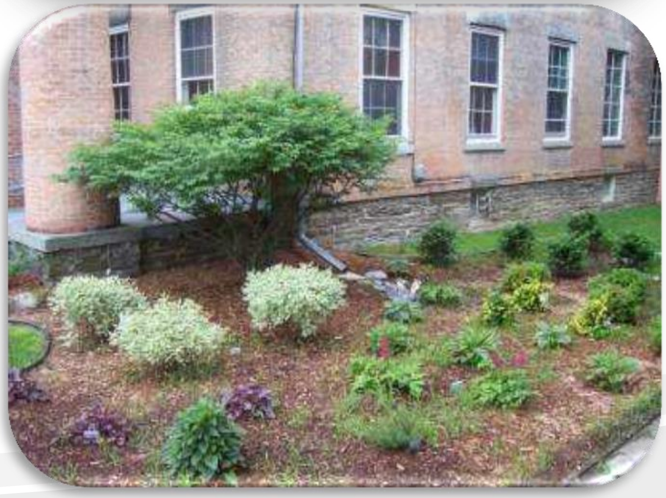
DESIGN FACTOR	SIMPLE DISCONNECTION
Maximum impervious (Rooftop) Area Treated	1,000 sq. ft. per disconnection
Longest flow path (roof/gutter)	75 feet
Disconnection Length	Equal to longest flow path, but no less than 40 feet [2]
Disconnection slope	< 2%, or < 5% with turf reinforcement [3]
Distance from buildings or foundations	Extend downspouts 5 ft. [4] (15 ft. in karst areas) away from building *if grade is less than 1%.*
Type of Pretreatment	External (leaf screens, etc)

[1] For alternative runoff reduction practices, see the applicable specification for design criteria. See Table 1 in this specification for eligible practices and associated specification numbers.

[2] An alternative runoff reduction practice must be used when the disconnection length is less than 40 feet.

[3] Turf reinforcement may include EC-2, EC-3, or other appropriate reinforcing materials that are confirmed by the designer to be non-erosive for the specific characteristics and flow rates anticipated at each individual application, and acceptable to the plan approving authority.

[4] Note that the downspout extension of 5 feet is intended for simple foundations. The use of a dry well or french drain adjacent to an in-ground basement or finished floor area should be carefully designed and coordinated with the design of the structure's water-proofing system (foundation drains, etc.), or avoided altogether.



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Rooftop/Impervious Area Disconnection

VIRGINIA DEQ STORMWATER DESIGN SPECIFICATION No. 1

Key Design Consideration: Application of maximum impervious area per disconnection requires larger sites (commercial or mixed use property) use Vegetated Filter Strips

Rooftop/Impervious Area Disconnection

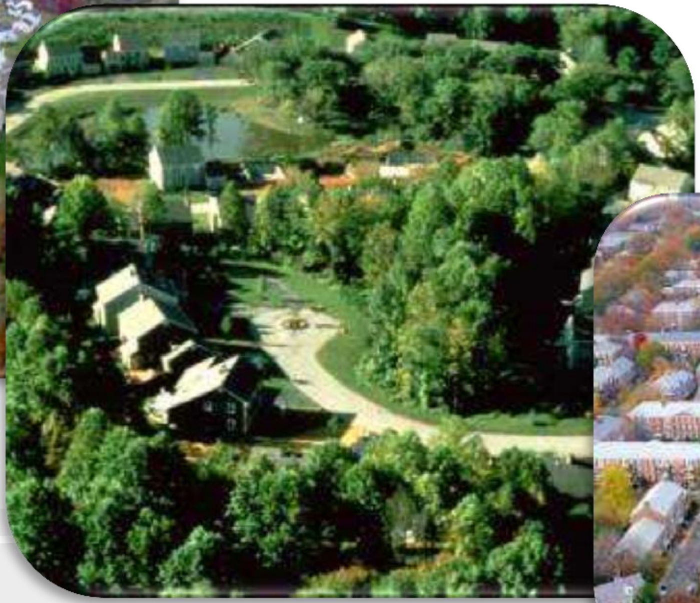
VIRGINIA DEQ STORMWATER DESIGN SPECIFICATION No. 1

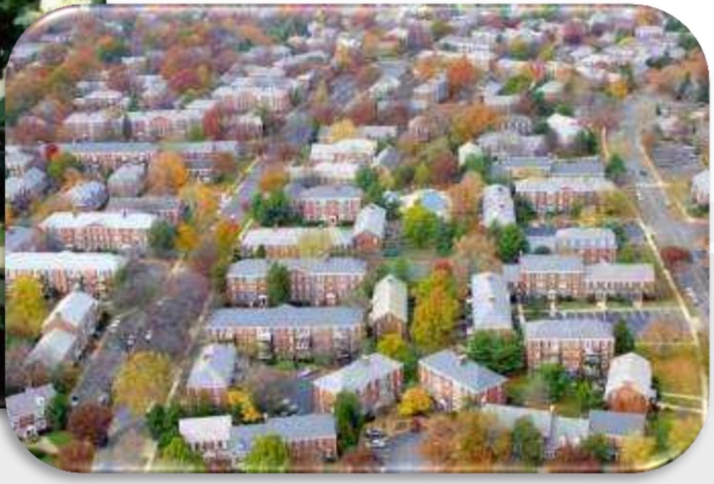
Key Design Consideration: Level spreader for concentrated flow (level spreader length should equal width of disconnection area)

Rooftop/Impervious Area Disconnection

VIRGINIA DEQ STORMWATER DESIGN SPECIFICATION No. 1

Key Design Consideration: Recommend minimum lot sizes (e.g. 6,000 ft^2) or go to alternative practices





Rooftop/Impervious Area Disconnection

VIRGINIA DEQ STORMWATER DESIGN SPECIFICATION No. 1

Alternate Disconnection: Utilize where space required for simple disconnection may not be available, or enhanced performance is desired <u>or required:</u>

- Amended Soil Flowpath
- Micro-Bioretention (Raingardens)
- Rainwater Harvesting & Cisterns;
- Micro-Infiltration (dry wells);
- Urban Planter

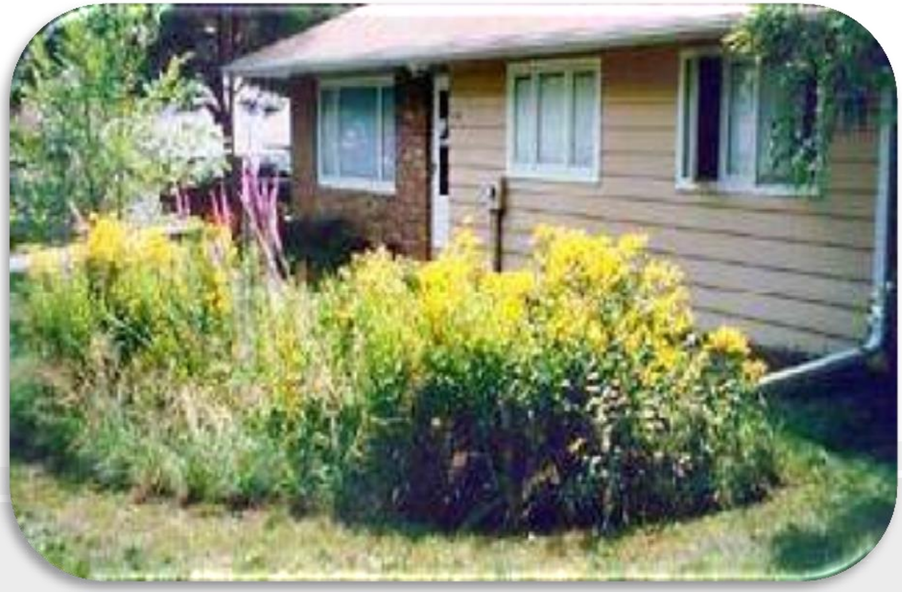
Performance Credit for Alternate Disconnection Practices as per micro-scale criteria for practice

Rooftop/Impervious Area Disconnection

VIRGINIA DEQ STORMWATER DESIGN SPECIFICATION No. 1

Alternate Disconnection:

- Rainwater Harvesting & Cisterns
- Micro-Infiltration (dry wells)
- Rain Gardens Urban Planter



Sheet Flow to a Vegetated Filter Strip or Conserved Open Space

VIRGINIA DEQ STORMWATER DESIGN SPECIFICATION No. 2

Sheet Flow to a Vegetated Filter Strip or Conserved Open Space

VIRGINIA DEQ STORMWATER DESIGN SPECIFICATION No. 2

Summary of Stormwater Functions [1]

Stormwater Function	Conservation Area		Vegetated Filter Strip	
	HSG Soils A and B	HSG Soils C and D	HSG Soils A	HSG Soils B [4], C and D
	Assume no CA [2] in Conservation Area		No CA [3]	With CA [2]
Annual Runoff Vol. Reduction (RR)	75%	50%	50%	50%
Total Phosphorus (TP) EMC Reduction[5] by BMP Treatment Process	0		0	
Total Phosphorus (TP) Mass Load Removal	75%	50%	50%	50%
Total Nitrogen (TN) EMC Reduction by BMP Treatment Process	0		0	
Total Nitrogen (TN) Mass Load Removal	75%	50%	50%	50%
Channel Protection and Flood Mitigation	**Partial.** Designers can use the VRRM Compliance spreadsheet to adjust curve number for each design storm for the contributing drainage area; *and* designers can account for a lengthened Time-of-Concentration flow path in computing peak discharge.			

[1] CWP and CSN (2008); CWP (2007)

[2] CA = Compost Amended Soils (see Design Specification No. 4)

[3] Compost amendments are generally not applicable for undisturbed A soils, although it may be advisable to incorporate them on mass-graded A or B soils and/or filter strips on B soils, in order to maintain runoff reduction rates.

[4] The plan approving authority may waive the requirement for compost amended soils for filter strips on B soils under certain conditions (see Section 6.2 below)

[5] There is insufficient monitoring data to assign a nutrient removal rate for filter strips at this time.

Sheet Flow to a Vegetated Filter Strip or Conserved Open Space

VIRGINIA DEQ STORMWATER DESIGN SPECIFICATION No. 2

Filter Strip & Open Space Design Criteria

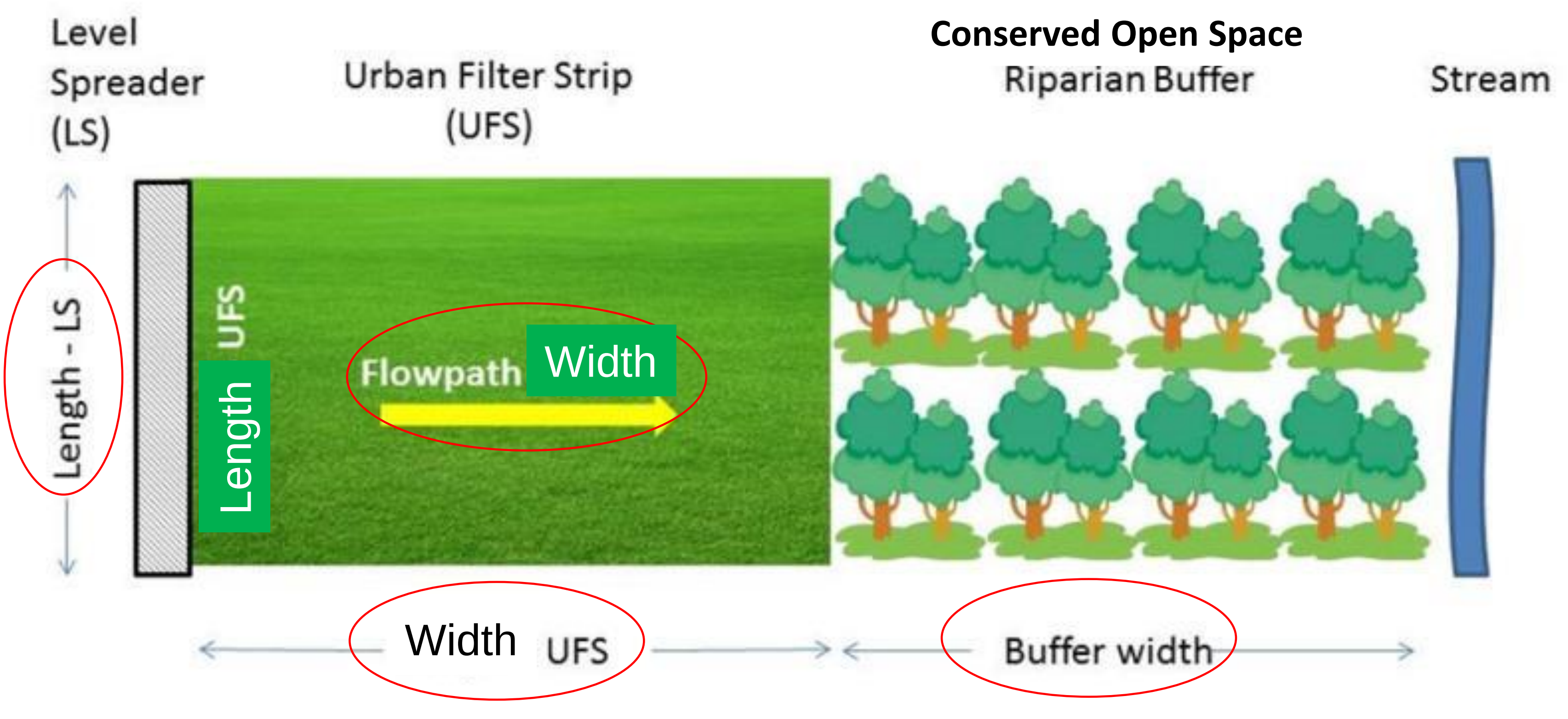
Design Issue	Conserved Open Space	Vegetated Filter Strip
Soil and Vegetative Cover (Sections 6.1 and 6.2)	Undisturbed soils and native vegetation	Amended soils and dense turf cover or landscaped with herbaceous cover, shrubs, and trees
Overall Slope and Width (perpendicular to the flow) (Section 5)	0.5% to 3% Slope – Minimum 35 ft width 3% to 6% Slope – Minimum 50 ft width The first 10 ft. of filter must be 2% or less in all cases [2]	1% [1] to 4% Slope – Minimum 35 ft. width 4% to 6% Slope – Minimum 50 ft. width 6% to 8% Slope – Minimum 65 ft. width The first 10 ft. of filter must be 2% or less in all cases
Sheet Flow (Section 5)	Maximum flow length of 150 ft. from adjacent pervious areas; Maximum flow length of 75 ft. from adjacent impervious areas	
Concentrated Flow (Section 6.3)	Length of ELS [6] Lip = 13 lin. ft. per each 1 cfs of inflow if area has 90% Cover [3] Length = 40 lin. ft. per 1 cfs for forested or re-forested Areas [4] (ELS [6] length = 13 lin.ft. min; 130 lin.ft. max.)	Length of ELS [6] Lip = 13 lin.ft. per each 1 cfs of inflow (13 lin.ft. min; 130 lin.ft. max.)
Construction Stage (Section 8)	Located outside the limits of disturbance and protected by ESC controls	Prevent soil compaction by heavy equipment
Typical Applications (Section 5)	Adjacent to stream or wetland buffer or forest conservation area	Treat small areas of IC (e.g., 5,000 sf) and/or turf-intensive land uses (sports fields, golf courses) close to source
Compost Amendments (Section 6.1)	No	Yes (B, C, and D soils) [5]
Boundary Spreader (Section 6.3)	GD [6] at top of filter	GD [6] at top of filter PB [6] at toe of filter

[1] A minimum of 1% is recommended to ensure positive drainage.
[2] For Conservation Areas with a varying slope, a pro-rated length may be computed only if the first 10 ft. is 2% or less.
[3] Vegetative Cover is described in **Section 6.2**.
[4] Where the Conserved Open Space is a mixture of native grasses, herbaceous cover and forest (or re-forested area), the length of the ELS [6] Lip can be established by computing a weighted average of the lengths required for each vegetation type. Refer to **Section 6.3** for design criteria
[5] The plan approving authority may waive the requirement for compost amended soils for filter strips on B soils under certain conditions (see **Section 6.1**).
[6] ELS = Engineered Level Spreader; GD = Gravel Diaphragm; PB = Permeable Berm.

Sheet Flow to a Vegetated Filter Strip or Conserved Open Space

VIRGINIA DEQ STORMWATER DESIGN SPECIFICATION No. 2

Key Design Consideration: Nomenclature!



Sheet Flow to a Vegetated Filter Strip or Conserved Open Space

VIRGINIA DEQ STORMWATER DESIGN SPECIFICATION No. 2

Key Design Consideration:

Minimum filter strip length (based on filter strip or open space grade)

Boundary zone (or pre-treatment area) contained in first 10 ft at minimum grade (2 – 4%)

Photo: R. Winston; BAE Stormwater Engineering Group, NCSU

Sheet Flow to a Vegetated Filter Strip or Conserved Open Space

VIRGINIA DEQ STORMWATER DESIGN SPECIFICATION No. 2

Key Design Consideration:

- Maximum drainage area/contributing flow path:
  - Sheet Flow (75’ or 150’)
  - Concentrated Flow (based on 130’ max ELS)

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Sheet Flow to a Vegetated Filter Strip or Conserved Open Space

VIRGINIA DEQ STORMWATER DESIGN SPECIFICATION No. 2

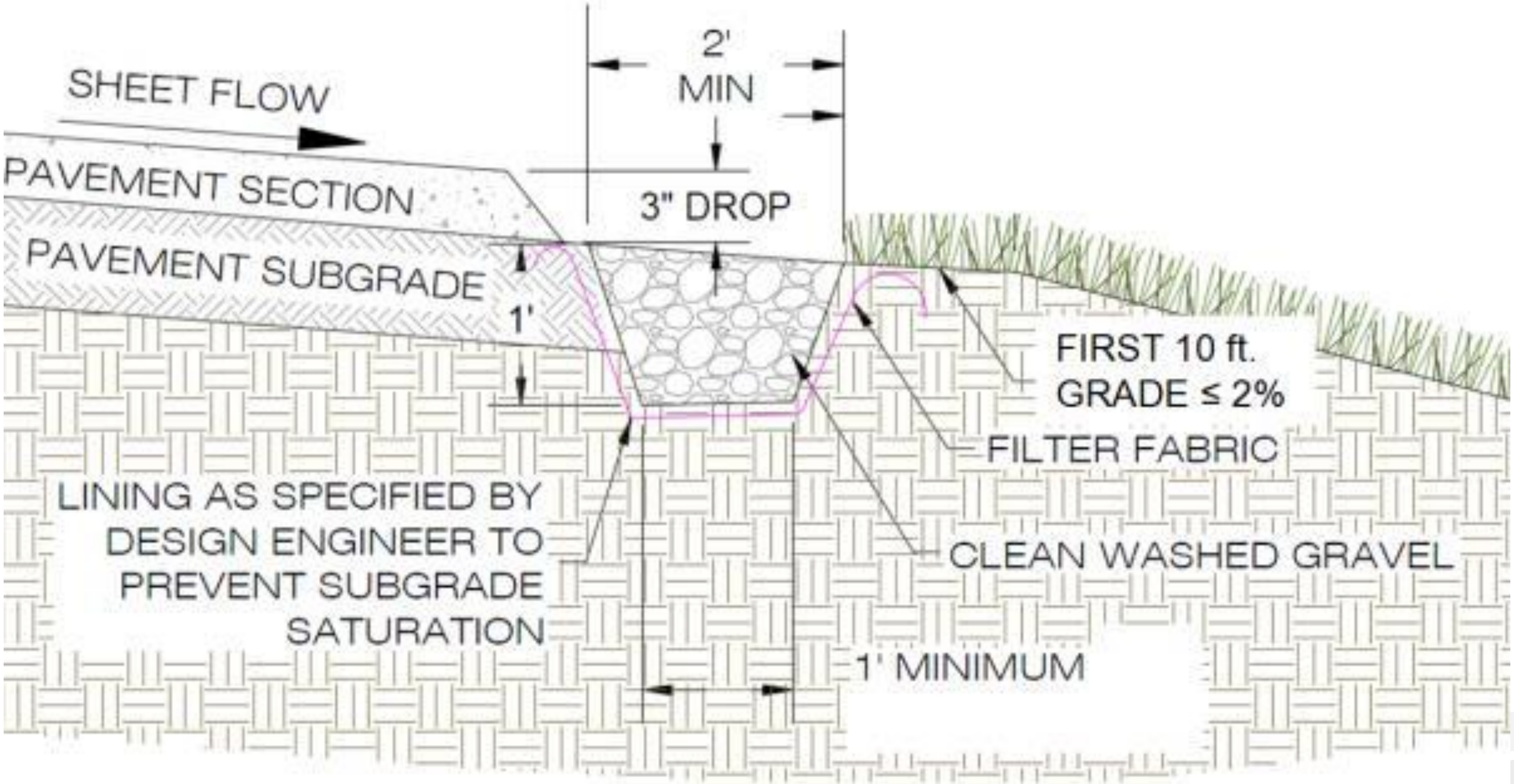
Key Design Consideration:

Gravel diaphragm at upper edge to ensure runoff enters as sheet flow

Photo: BAE Stormwater Engineering Group, NCSU

Sheet Flow to a Vegetated Filter Strip or Conserved Open Space

VIRGINIA DEQ STORMWATER DESIGN SPECIFICATION No. 2



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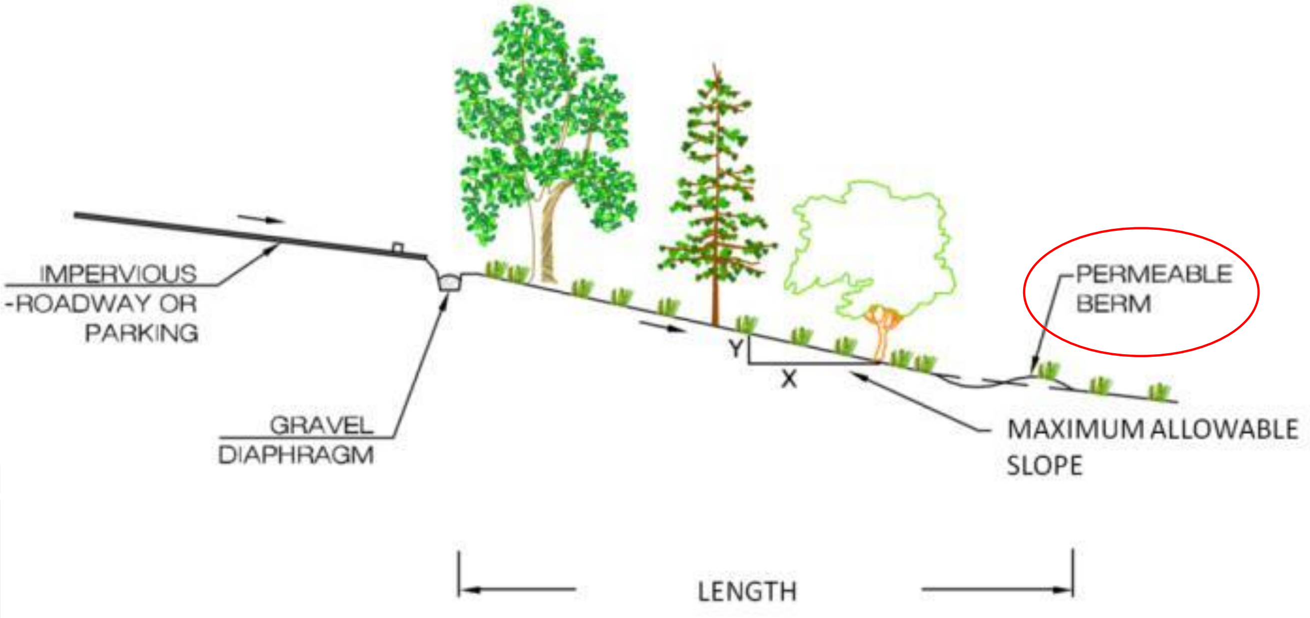
Sheet Flow to a Vegetated Filter Strip or Conserved Open Space

VIRGINIA DEQ STORMWATER DESIGN SPECIFICATION No. 2

Key Design Consideration:

Policy for conditions downstream edge of filter strip or conserved open space to require permeable berm



Sheet Flow to a Vegetated Filter Strip or Conserved Open Space

VIRGINIA DEQ STORMWATER DESIGN SPECIFICATION No. 2

Key Design Consideration:

Establish or maintain good vegetative cover and limit grade to keep flow velocity low and maintain sheet flow

- Gravel diaphragm
- Flat grade
- Thick no-mow (low maintenance) vegetation

Sheet Flow to a Vegetated Filter Strip or Conserved Open Space

VIRGINIA DEQ STORMWATER DESIGN SPECIFICATION No. 2

Key Design Consideration:

Engineered Level Spreader (ELS) combined with forebay, energy dissipater, rigid lip, & gravel diaphragm

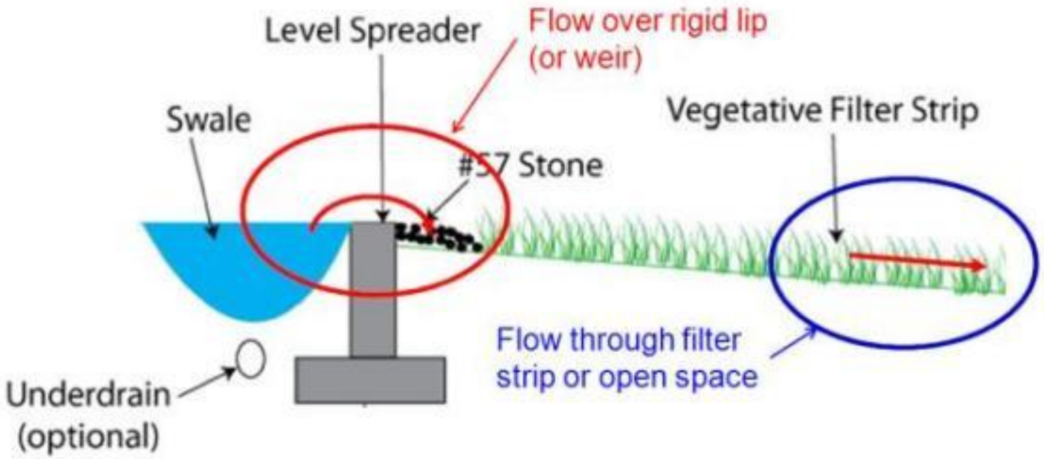


Photo: R. Winston; BAE Stormwater Engineering Group, NCSU

Sheet Flow to a Vegetated Filter Strip or Conserved Open Space

VIRGINIA DEQ STORMWATER DESIGN SPECIFICATION No. 2

Key Design Consideration:

- Length of ELS = 13 ft for every 1 cfs of design flow (recommended maximum = 130 ft);
- Design length based on:
  - Limiting flow velocity over rigid lip (weir) to 1 ft/s
  - Depth of flow over (broad crested) weir to approx. 1”
  - Maintain non-erosive design velocity (grass cover) to < 4 fps

Sheet Flow to a Vegetated Filter Strip or Conserved Open Space

VIRGINIA DEQ STORMWATER DESIGN SPECIFICATION No. 2

Key Design Consideration:

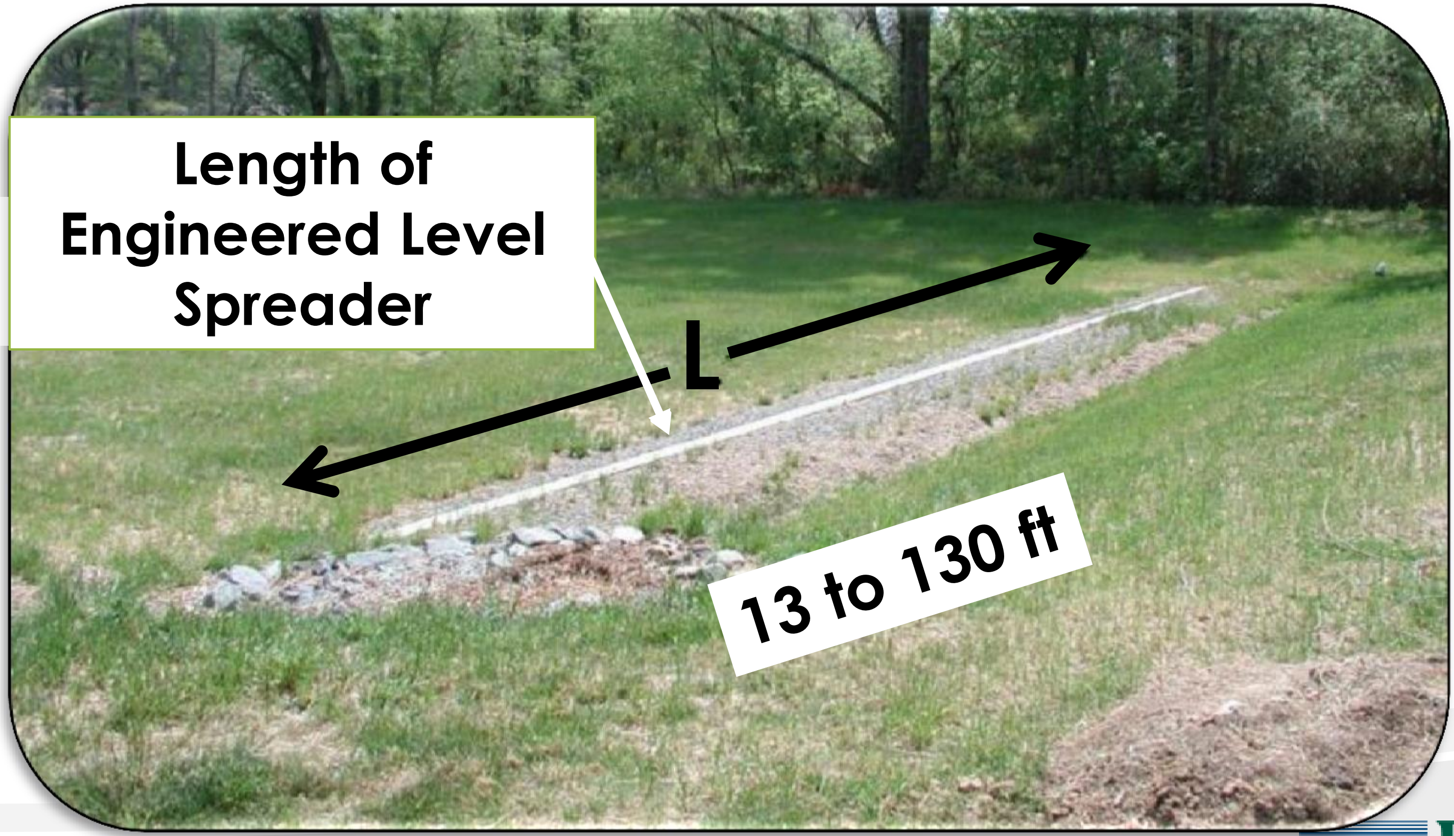


Photo: R. Winston; BAE Stormwater Engineering Group, NCSU

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Grass Channels

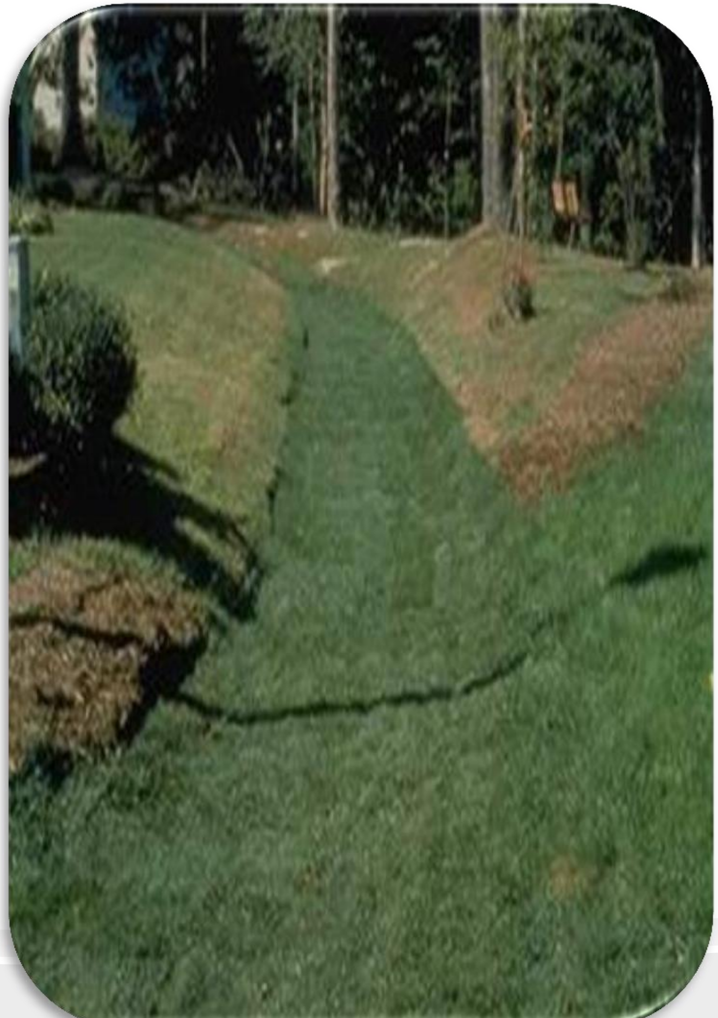
VIRGINIA DEQ STORMWATER DESIGN SPECIFICATION No. 3

VIRGINIA DEPARTMENT OF ENVIRONMENTAL QUALITY

Grass Channels

VIRGINIA DEQ STORMWATER DESIGN SPECIFICATION No. 3

Summary of Stormwater Functions [1]



Stormwater Function	HSG Soils A and B		HSG Soils C and D	
	No CA [2]	With CA	No CA	With CA
Annual Runoff Volume Reduction (RR)	20%	NA [3]	10%	30%
Total Phosphorus (TP) EMC Reduction[4] by BMP Treatment Process	15%		15%	
Total Phosphorus (TP) Mass Load Removal	32%		24% (no CA) to 41% (with CA)	
Total Nitrogen (TN) EMC Reduction[4] by BMP Treatment Process	20%		20%	
Total Nitrogen (TN) Mass Load Removal	36%		28% (no CA) to 44% (with CA)	
Channel & Flood Protection	**Partial.** Designers can use the RRM spreadsheet to adjust curve number for each design storm for the contributing drainage area, based on annual runoff reduction achieved. Also, the Tc for the grass swale flow path should reflect the slope and appropriate roughness for the intended vegetative cover.			

[1] CWP and CSN (2008) and CWP (2007).

[2] CA= Compost Amended Soils, see Stormwater Design Specification No. 4.

[3] Compost amendments are generally not applicable for A and B soils, although it may be advisable to incorporate them on mass-graded and/or excavated soils to maintain runoff reduction rates. In these cases, the 30% runoff reduction rate may be claimed, regardless of the pre-construction HSG.

[4] Change in event mean concentration (EMC) through the practice. Actual nutrient mass load removed is the product of the pollutant removal rate and the runoff volume reduction rate (see Table 1 in the *Introduction to the New Virginia Stormwater Design Specifications*).

Grass Channels

VIRGINIA DEQ STORMWATER DESIGN SPECIFICATION No. 3

Grass Channel design criteria:

- **Bottom width (4 ft min, 8 ft max) set to maintain treatment volume (T_v)[1] peak flow ($Q_{1\text{-inch}}$) at less than 4 inches depth and ≤ 1 ft/s velocity.**
- Channel side-slopes 3H:1V or flatter
- Maximum total contributing drainage area ≤ 5 acres

[1] Design should consider entire T_v of contributing drainage area (rather than Tv_{BMP} which would reflect T_v decrease based on upstream runoff reduction practices) in order to ensure non-erosive conveyance during all design storm conditions.

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Grass Channels

VIRGINIA DEQ STORMWATER DESIGN SPECIFICATION No. 3

Grass Channel design criteria:

- Longitudinal slope ≤ 4%. (Check dams may be used to reduce effective slope to meet limiting velocity requirements)

- Dimensions to ensure flow velocity non-erosive during 2 & 10-year design storm and 10-year design flow contained within channel (minimum of 0.3 ft freeboard)

Grass Channels

VIRGINIA DEQ STORMWATER DESIGN SPECIFICATION No. 3

Key Design Consideration:

- Maximum width of bottom of trapezoidal geometry should be limited to discourage braided flow and preferential channeling within grass channel

Grass Channels

VIRGINIA DEQ STORMWATER DESIGN SPECIFICATION No. 3

Key Design Consideration:

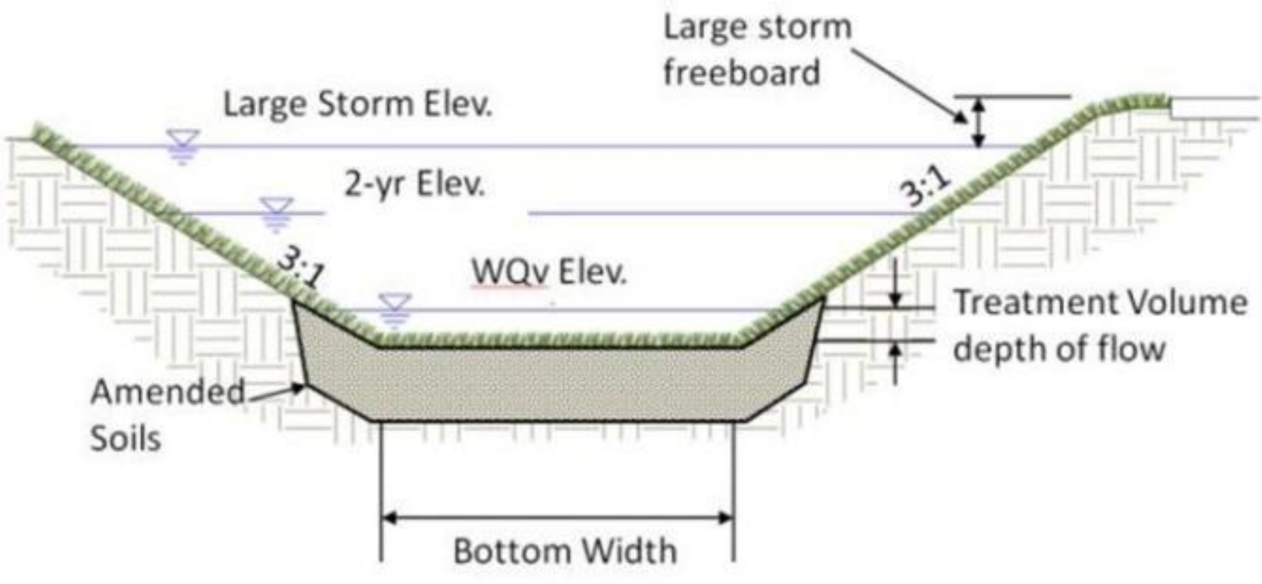
- Most grass channels gradually evolve to parabolic shape in response to flow characteristics
- Water quality grass channel should still be constructed trapezoidal

Grass Channels

VIRGINIA DEQ STORMWATER DESIGN SPECIFICATION No. 3

Key Design Consideration: Soils

- Runoff reduction (RR) capacity greatest in HSG A soils
- RR gradually decreases in HSG B, C and D soils
- HSG C and D soils lining bottom of Grass Channel can be amended to improve RR performance



Soil Amendments

VIRGINIA DEQ STORMWATER DESIGN SPECIFICATION No. 4

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Soil Amendments

VIRGINIA DEQ STORMWATER DESIGN SPECIFICATION No. 4

Summary of Stormwater Functions [1]

Stormwater Function	HSG Soils A and B		HSG Soils C and D	
	No CA [2]	With CA	No CA	With CA
Annual Runoff Volume Reduction (RR)				
Simple Rooftop Disconnection	**50%**	**NA** [3]	**25%**	**50%**
Filter Strip	**50%**	**NA** [3]	**NA** [4]	**50%**
Grass Channel	**20%**	**NA** [3]	**10%**	**30%**
Total Phosphorus (TP) EMC Reduction[4] by BMP Treatment Practice	**0**		**0**	
Total Phosphorus (TP) Mass Load Removal	**Same as for RR (above)**		**Same as for RR (above)**	
Total Nitrogen (TN) EMC Reduction by BMP Treatment Practice	**0**		**0**	
Total Nitrogen (TN) Mass Load Removal	**Same as for RR (above)**		**Same as for RR (above)**	
Channel Protection & Flood Mitigation	**Partial.** Designers can use the RRM spreadsheet to adjust the curve number for each design storm for the contributing drainage area, based on annual runoff volume reduction achieved.			

[1] CWP and CSN (2008), CWP (2007)

[2] CA = Compost Amended Soils,

[3] Compost amendments are generally not applicable for A and B soils, although it may be advisable to incorporate them on mass-graded B soils to maintain runoff reduction rates.

[4] Filter strips in HSG C and D should use composted amended soils to enhance runoff reduction capabilities. See Stormwater Design Specification No. 2: Sheetflow to Vegetated Filter Strip or Conserved Open Space.

Soil Amendments

VIRGINIA DEQ STORMWATER DESIGN SPECIFICATION No. 4

Short-Cut Method to Determine Compost and Incorporation Depths

	Contributing Impervious Cover to Soil Amendment Area Ratio [1]			
	IC/SA = 0 [2]	IC/SA = 0.5	IC/SA = 0.75	IC/SA = 1.0 [3]
Compost (in) [4]	2 to 4 [5]	3 to 6 [5]	4 to 8 [5]	6 to 10 [5]
Incorporation Depth (in)	6 to 10 [5]	8 to 12 [5]	15 to 18 [5]	18 to 24 [5]
Incorporation Method	Rototiller	Tiller	Subsoiler	Subsoiler

Notes:

1 IC = contrib. impervious cover (sq. ft.) and SA = surface area of compost amendment (sq. ft.)

2 For amendment of compacted lawns that do not receive off-site runoff

3 In general, IC/SA ratios greater than 1 should be avoided, unless applied to a simple rooftop disconnection

4 Average depth of compost added

5 Lower end for B soils, higher end for C/D soils

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Soil Amendments

VIRGINIA DEQ STORMWATER DESIGN SPECIFICATION No. 4

Criteria for applicability and design related to soil testing and compost material specifications.

Photo Credit: Richard McLaughlin, Ph.D., North Carolina State University

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Soil Amendments

VIRGINIA DEQ STORMWATER DESIGN SPECIFICATION No. 4

Criteria for applicability and design related to incorporating amendments

Photo Credit: Jeremy Balousek, P.E., Dane County, WI Land and Water Resources Department

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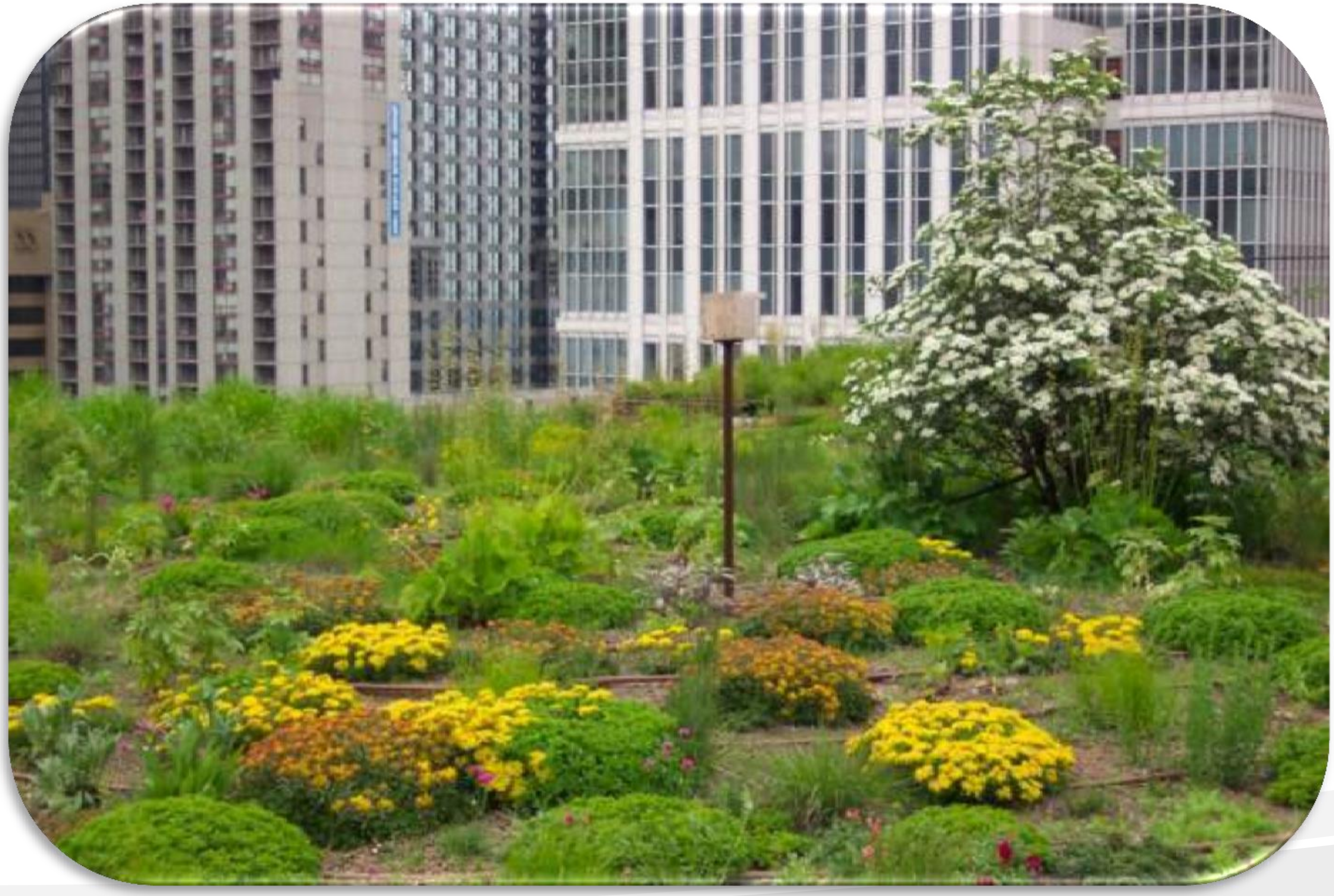
Vegetated Roof

VIRGINIA DEQ STORMWATER DESIGN SPECIFICATION No. 5



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Vegetated Roof

VIRGINIA DEQ STORMWATER DESIGN SPECIFICATION No. 5

Summary of Stormwater Functions [1]

Stormwater Function	Level 1 Design	Level 2 Design
Annual Runoff Volume Reduction (RR)	45%	60%
Total Phosphorus (TP) EMC Reduction[2] by BMP Treatment Process	0	0
Total Phosphorus (TP) Mass Load Removal	45%	60%
Total Nitrogen (TN) EMC Reduction[2] by BMP Treatment Process	0	0
Total Nitrogen (TN) Mass Load Removal	45%	60%
Channel Protection & Flood Mitigation [3]	Use the following Curve Numbers (CN) for Design Storm events: 1-year storm = 64; 2-year storm = 66; 10-year storm = 72; and the 100 year storm = 75	

[1] Sources: CWP and CSN (2008) and CWP (2007).

[2] Moran et al (2004) and Clark et al (2008) indicate no nutrient reduction or even negative nutrient reduction (due to leaching from the media) in early stages of vegetated roof development.

[3] See Miller (2008), NVRC (2007) and MDE (2008)

Vegetated Roof

VIRGINIA DEQ STORMWATER DESIGN SPECIFICATION No. 5

Vegetated Roof Design Criteria

Level 1 Design (RR:45; TP:0; TN:0)	Level 2 Design (RR: 60; TP:0; TN:0)
Tv = 1.0 (Rv)[1] (A)/12	Tv = 1.1 (Rv)[1] (A)/12
Depth of media up to 4 inches	Media depth 4 to 8 inches
Drainage System	2-inch stone drainage layer
No more than 20% organic matter in media	No more than 10% organic matter in media
All Designs: Must be in conformance to ASTM (2005) International Green (Vegetated) Roof Stds.	
[1]Rv represents the runoff coefficient for a conventional roof, which will usually be 0.95. The runoff reduction rate applied to the vegetated roof is for "capturing" the Treatment Volume (Tv) compared to what a conventional roof would produce as runoff.	

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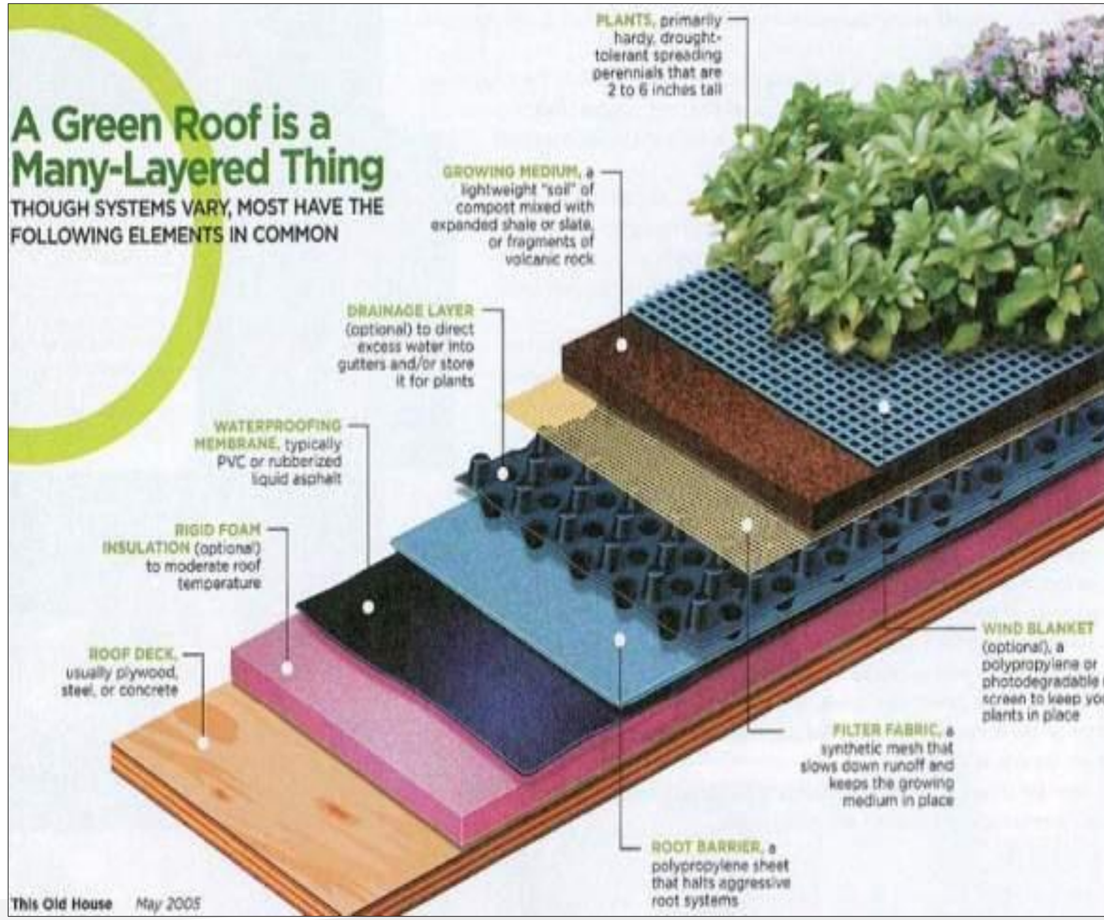
Vegetated Roof

VIRGINIA DEQ STORMWATER DESIGN SPECIFICATION No. 5

Functional Elements of Vegetated Roof:

- Deck layer
- Waterproofing layer
- Insulation layer
- Root barrier
- Drainage layer and drainage system
- Root permeable filter fabric
- Growing media
- Plant pallet



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Vegetated Roof

VIRGINIA DEQ STORMWATER DESIGN SPECIFICATION No. 5

Key Design Consideration:

- Structural capacity of roof
- Roof Access: construct & maintain
- Setbacks from electrical and HVAC systems, and vegetation-free zones (firebreaks, perimeter, etc.)

VIRGINIA DEPARTMENT OF ENVIRONMENTAL QUALITY

Rainwater Harvesting

VIRGINIA DEQ STORMWATER DESIGN SPECIFICATION No. 6

Rainwater Harvesting

VIRGINIA DEQ STORMWATER DESIGN SPECIFICATION No. 6

Summary of Stormwater Functions [1]

Stormwater Function	Performance
Annual Runoff Volume Reduction (RR)	Variable up to 90% [2]
Total Phosphorus (TN) EMC Reduction[1] by BMP Treatment Process	0%
Total Phosphorus (TN) Mass Load Removal	Variable up to 90% [2]
Total Nitrogen (TN) EMC Reduction[1] by BMP Treatment Process	0%
Total Nitrogen (TN) Mass Load Removal	Variable up to 90% [2]
Channel Protection	Partial: reduced curve numbers and increased Time of Concentration
Flood Mitigation	Partial: reduced curve numbers and increased Time of Concentration

[1] Nutrient mass load removal is equal to the runoff volume reduction rate. Zero pollutant removal rate is applied to the rainwater harvesting system only. Nutrient removal rates for secondary practices will be in accordance with the design criteria for those practices.

[2] Credit is variable and determined using the Cistern Design Spreadsheet. Credit up to 90% is possible if all water from storms with rainfall of 1 inch or less is used through demand, and the tank is sized such that no overflow from this size event occurs. The total credit may not exceed 90%.

Rainwater Harvesting

VIRGINIA DEQ STORMWATER DESIGN SPECIFICATION No. 6

Physical Feasibility and Applications

- Available space
- Site topography and hydraulic head
- Water table
- Soils
- Proximity of underground utilities.
- Contributing drainage area
- Rooftop material
- Rainwater water quality
- Hotspot land uses
- Setbacks from buildings
- Vehicle loading

VIRGINIA DEPARTMENT OF ENVIRONMENTAL QUALITY

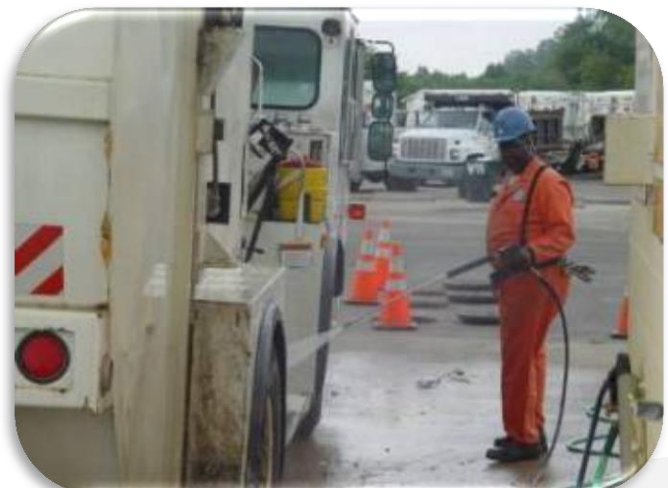
Rainwater Harvesting

VIRGINIA DEQ STORMWATER DESIGN SPECIFICATION No. 6

Annual runoff reduction volume credit only awarded for dedicated year-round water drawdown/demand

Laundry washing

Toilet flushing



Vehicle washing

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Rainwater Harvesting

VIRGINIA DEQ STORMWATER DESIGN SPECIFICATION No. 6

Seasonal uses must be supplemented with runoff reduction drawdown practice

Cooling tower make-up water

Irrigation

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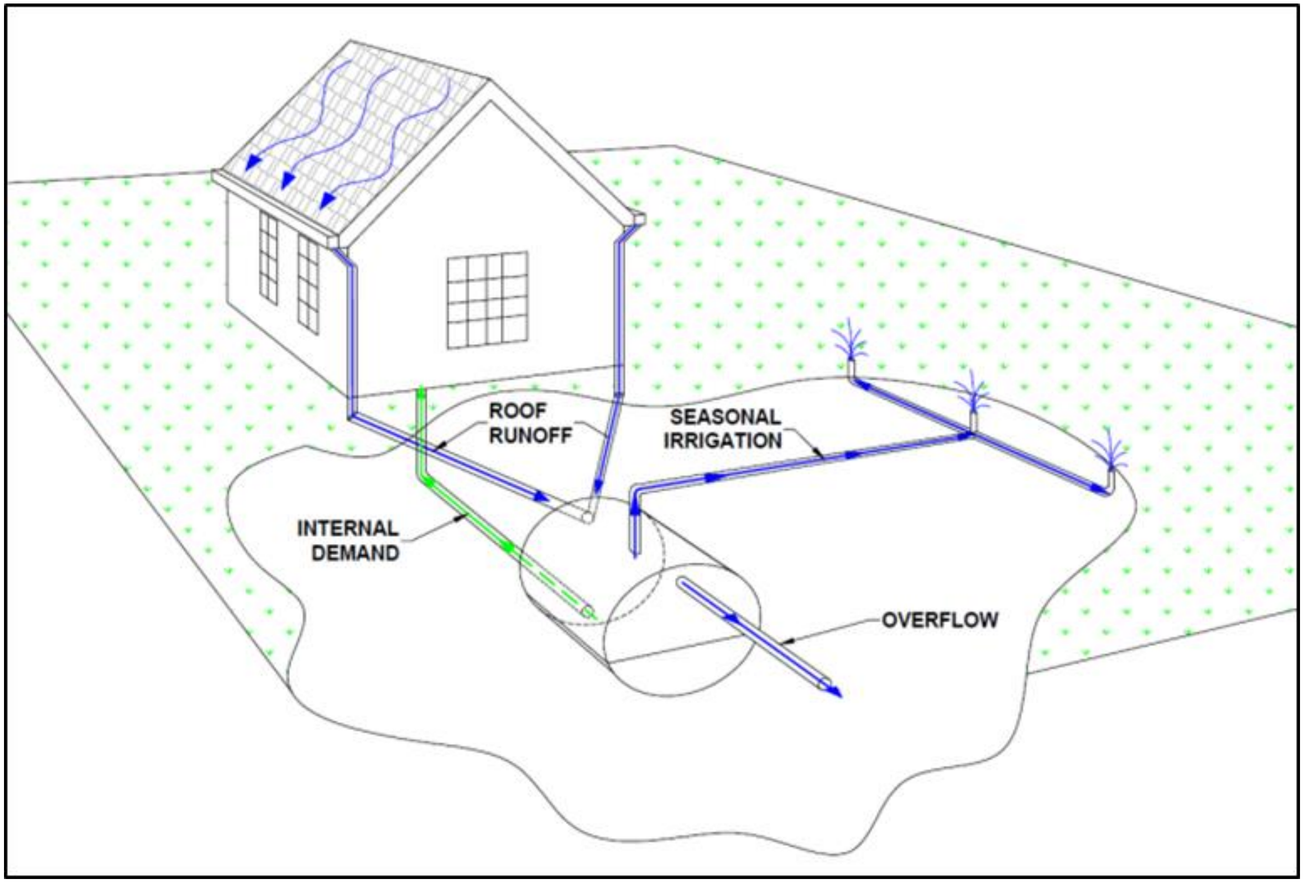
Rainwater Harvesting

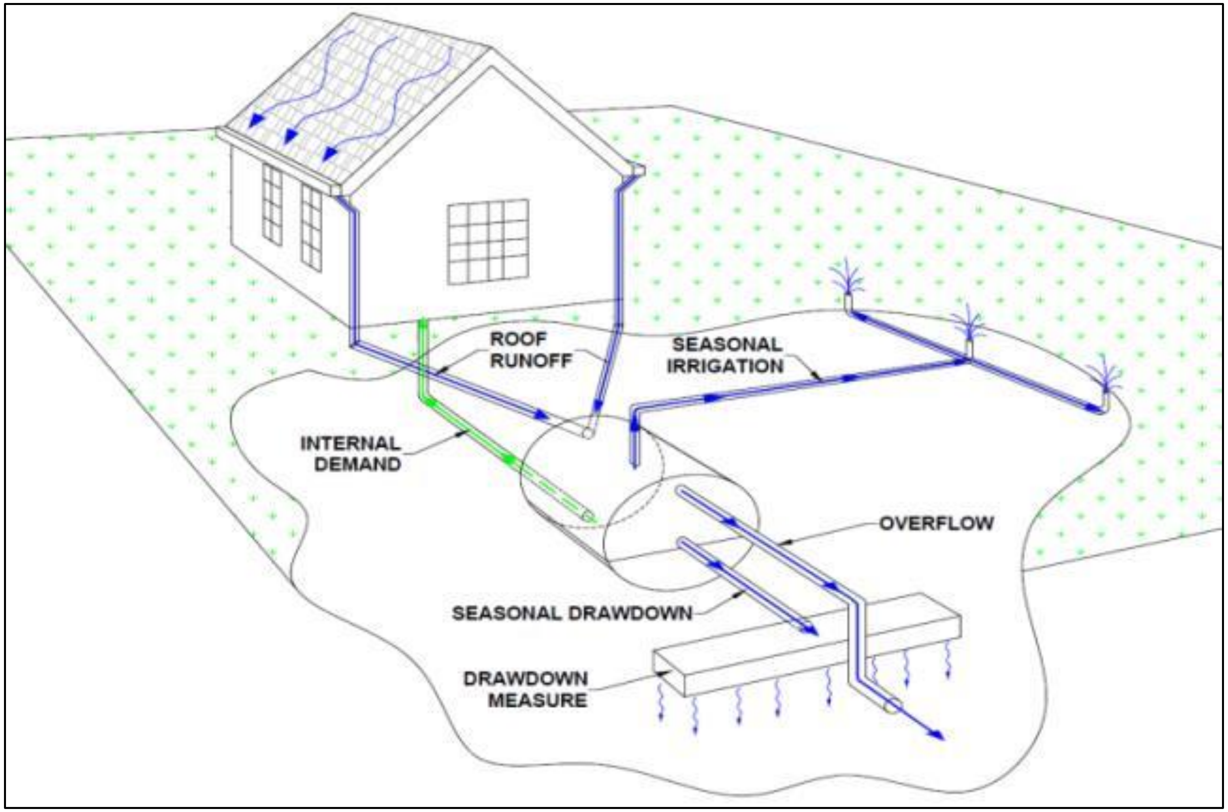
VIRGINIA DEQ STORMWATER DESIGN SPECIFICATION No. 6



Configuration 1: Year-round indoor use - optional seasonal outdoor use

Rainwater Harvesting

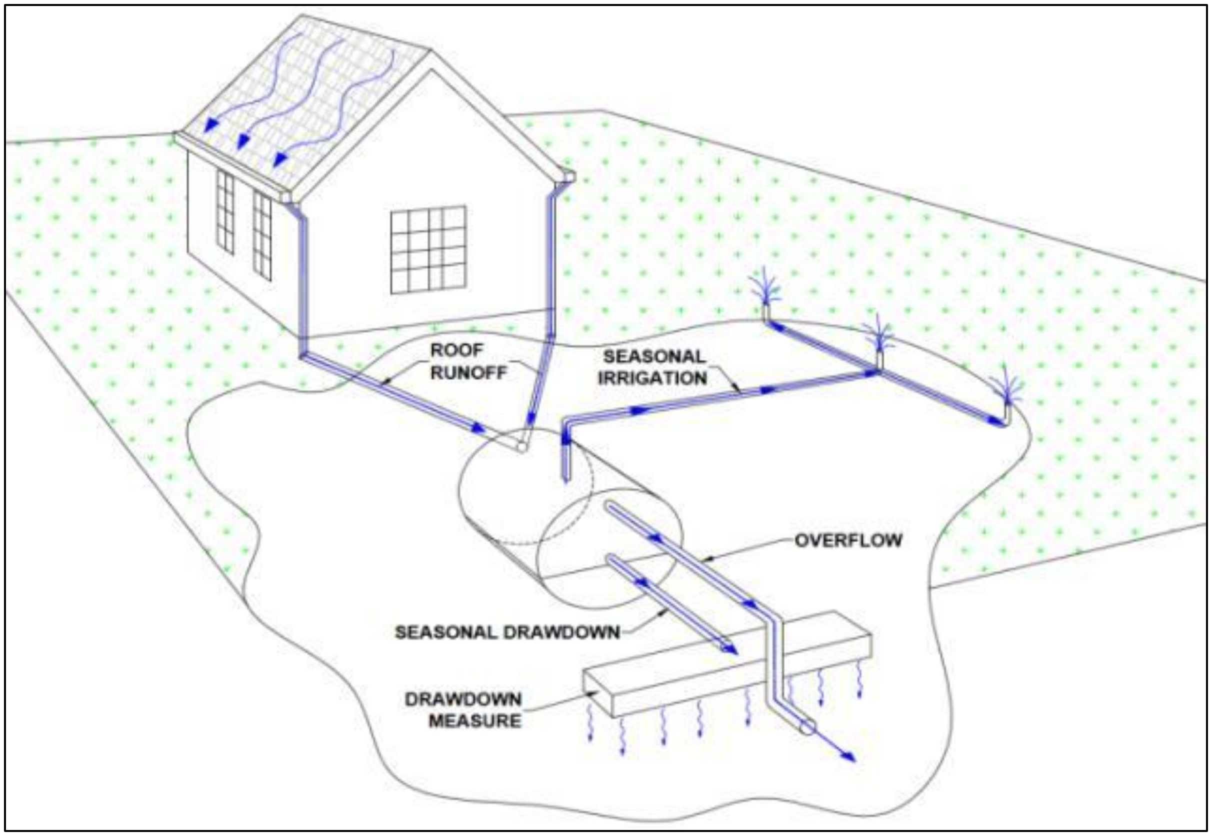
VIRGINIA DEQ STORMWATER DESIGN SPECIFICATION No. 6



Configuration 2: Year-round indoor use - seasonal indoor and/or outdoor uses supplemented with secondary runoff reduction drawdown practice

Rainwater Harvesting

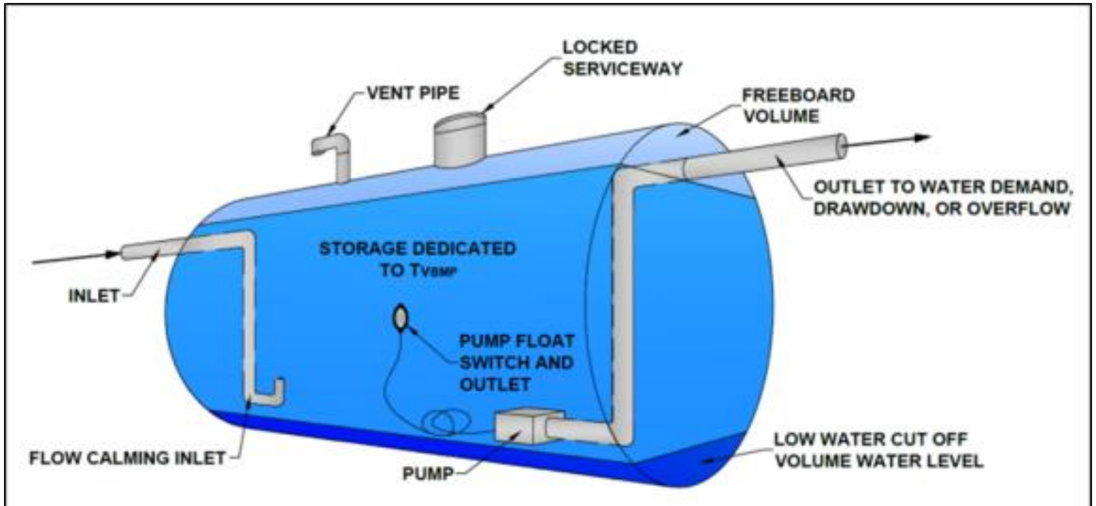
VIRGINIA DEQ STORMWATER DESIGN SPECIFICATION No. 6



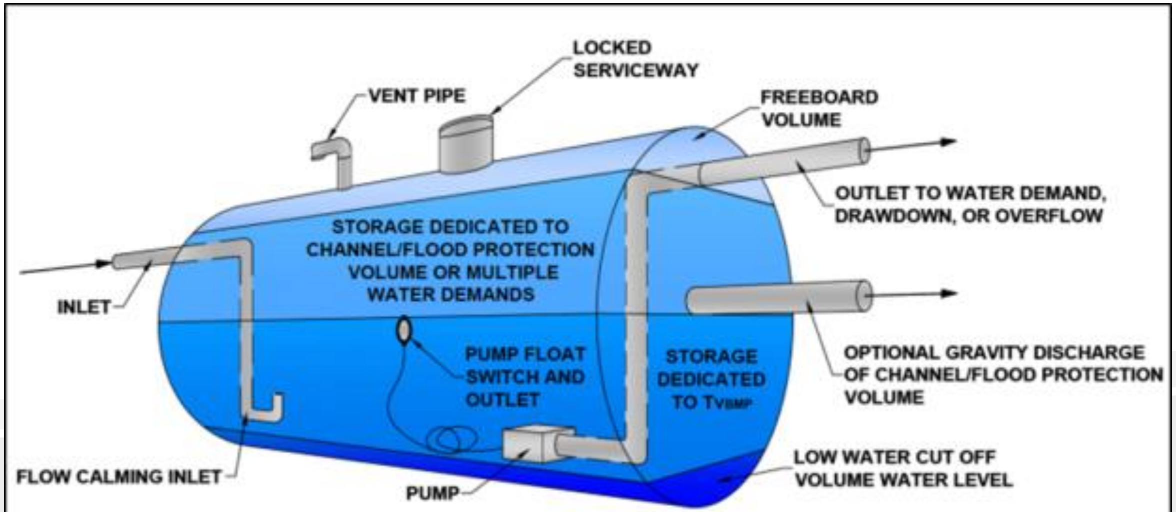
Configuration 3: Seasonal only indoor and/or outdoor uses supplemented with secondary runoff reduction drawdown practice

Rainwater Harvesting

VIRGINIA DEQ STORMWATER DESIGN SPECIFICATION No. 6



Tank Design 1: Storage Associated with Treatment Volume (Tv) only



Tank Design 2: Storage Associated with Treatment, Channel Protection and Flood Volume

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Permeable Pavement

VIRGINIA DEQ STORMWATER DESIGN SPECIFICATION No. 7

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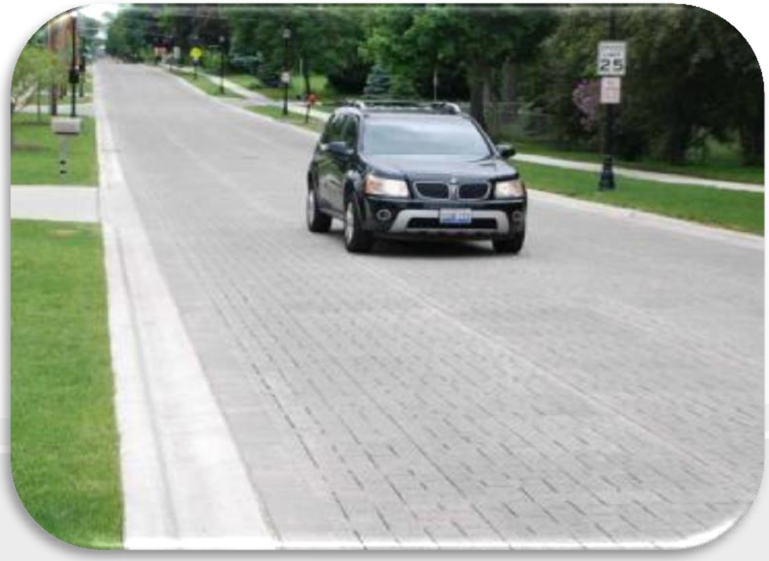
Permeable Pavement

VIRGINIA DEQ STORMWATER DESIGN SPECIFICATION No. 7



Summary of Stormwater Functions [1]

Stormwater Function	Level 1 Design	Level 2 Design
Annual Runoff Volume Reduction (RR)	45%	75%
Total Phosphorus (TP) EMC Reduction[1] by BMP Treatment Process	25%	25%
Total Phosphorus (TP) Mass Load Removal	59%	81%
Total Nitrogen (TN) EMC Reduction[1]	25%	25%
Total Nitrogen (TN) Mass Load Removal	59%	81%
Channel Protection	• Use VRRM Compliance spreadsheet to calculate a Curve Number (CN) adjustment[2]; ***OR*** • Design extra storage in the stone underdrain layer and peak rate control structure (optional, as needed) to accommodate detention of larger storm volumes.	
Flood Mitigation	Partial. May be able to design additional storage into the reservoir layer by adding perforated storage pipe or chambers.	

[1] Change in event mean concentration (EMC) through the practice. Actual nutrient mass load removed is the product of the removal rate and the runoff reduction rate (see Table 1 in the *Introduction to the New Virginia Stormwater Design Specifications*).

[2] NRCS TR-55 Runoff Equations 2-1 thru 2-5 and Figure 2-1 can be used to compute a curve number adjustment for larger storm events based on the retention storage provided by the practice(s).

Sources: CWP and CSN (2008) and CWP (2007)

Permeable Pavement

VIRGINIA DEQ STORMWATER DESIGN SPECIFICATION No. 7

Type of pavement materials

Concrete Grid Pavers

Pervious Concrete

Porous Asphalt

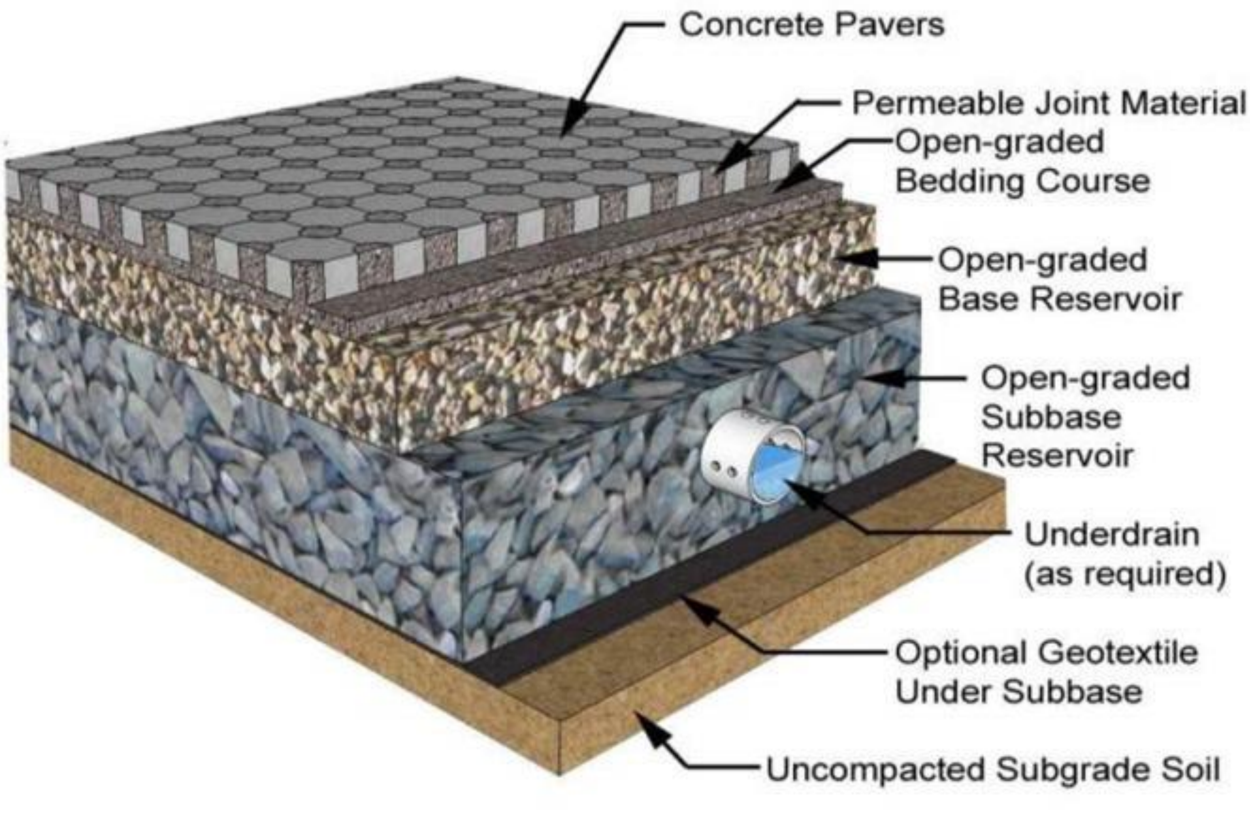
Permeable Interlocking Concrete Pavers

Pervious Composites

Permeable Rubber Overlays

Permeable Pavement

VIRGINIA DEQ STORMWATER DESIGN SPECIFICATION No. 7



Permeable Pavement

VIRGINIA DEQ STORMWATER DESIGN SPECIFICATION No. 7

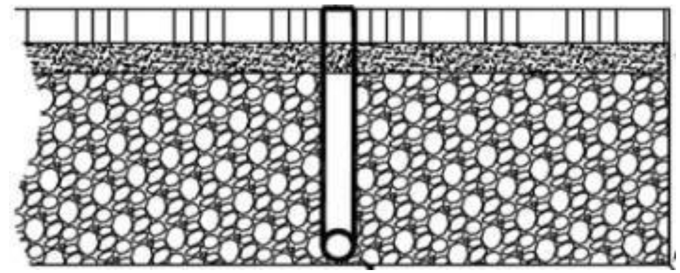
Permeable Pavement Design Criteria

Level 1 Design	Level 2 Design
$Tv_{BMP} = (1)(Rv)(A) / 12$ + any remaining volume from an upstream BMP(s) [1]	$Tv_{BMP} = (1.1)(Rv)(A) / 12$
Soil infiltration is less than 0.5 in./hr.	Soil infiltration rate exceeds 0.5 in./hr to remove underdrain requirement, or a drawdown design in accordance with **Section 6**.
Underdrain required	1. No underdrain; ***OR*** 2. If an underdrain is used, a 12-inch (minimum) stone reservoir infiltration sump below the underdrain invert that meets the drawdown requirements of Section 6 must be provided; ***OR*** 3. The Tv stone reservoir volume has at least a 48-hour drain time, as regulated by a control structure.
CDA[1] = The permeable pavement area plus upgradient parking, as long as the ratio of external contributing area to permeable pavement does not exceed 2:1.	CDA = The permeable pavement area;
[1] The contributing drainage area to the permeable pavements should be limited to paved surfaces in order to avoid sediment wash-on, and. When pervious areas are conveyed to permeable pavement, sediment source controls and/or pre-treatment must be provided. The pre-treatment may qualify for a runoff reduction credit if designed accordingly.	

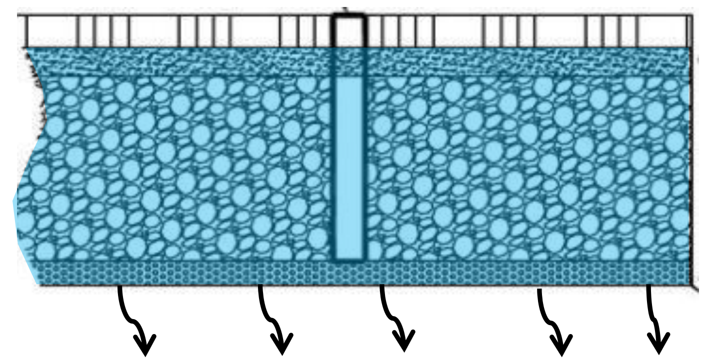
Permeable Pavement

VIRGINIA DEQ STORMWATER DESIGN SPECIFICATION No. 7

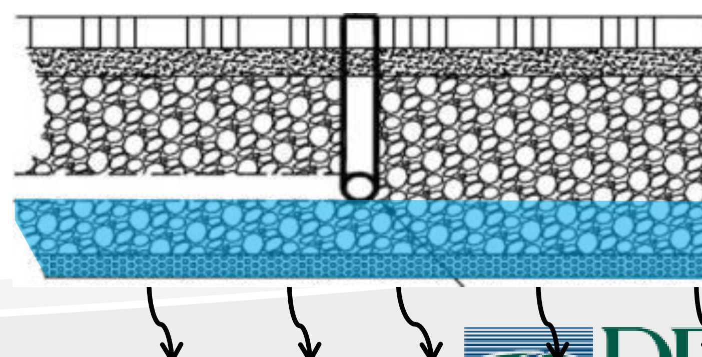
Level 1



Level 2 (infiltration)



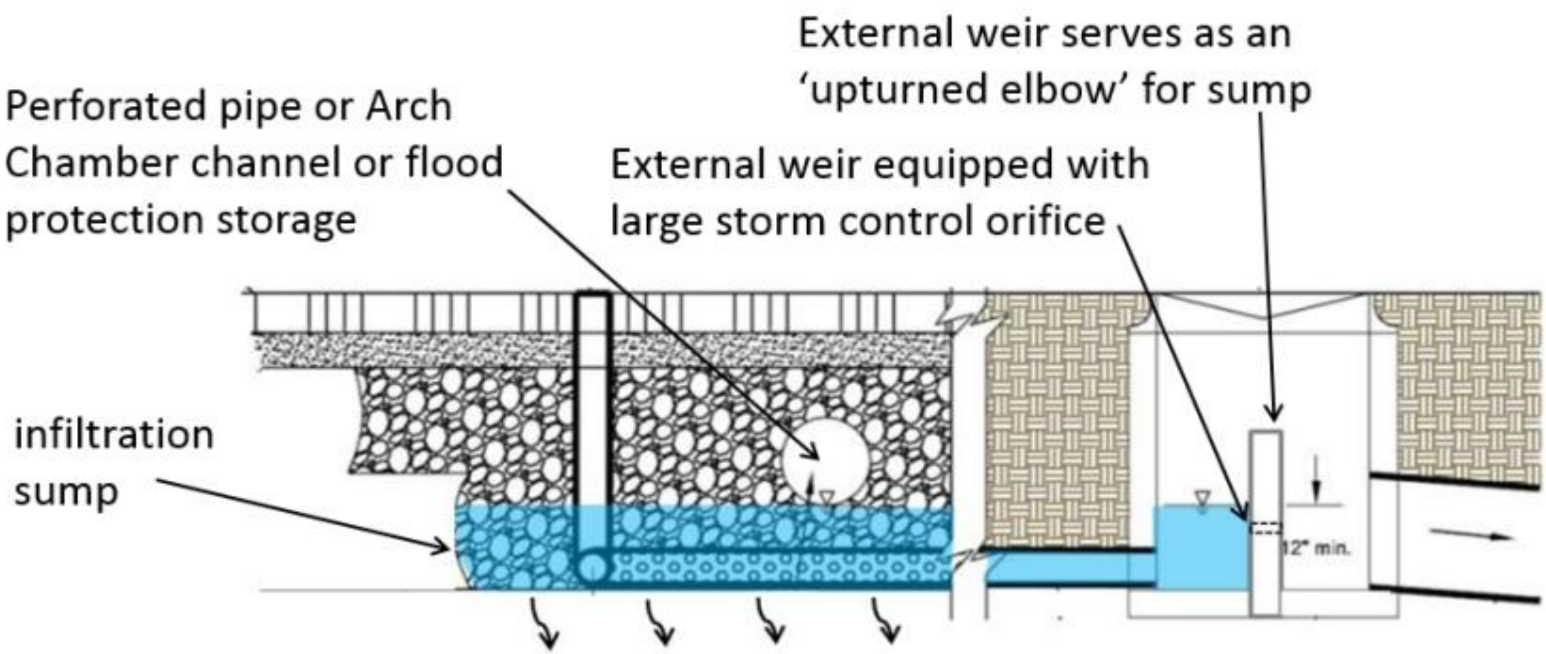
Level 2 (infiltration sump)



Permeable Pavement

VIRGINIA DEQ STORMWATER DESIGN SPECIFICATION No. 7

Key Design Consideration: 'Upturned Elbow'



Permeable Pavement

VIRGINIA DEQ STORMWATER DESIGN SPECIFICATION No. 7

Key Design Consideration: stone reservoir depth, d_p

$$d_p = \frac{\{(d_c \times R) + P - (i/2 \times t_f)\}}{V_r}$$

d_p = Depth of stone reservoir layer (ft.)

d_c = Depth of runoff from contributing drainage area (not including permeable paving surface) for Treatment Volume (Tv/A_c), or other design storm (ft.)

R = A_c/A_p = Ratio of contributing drainage area (A_c, not including permeable paving surface) to permeable pavement surface area (A_p)

P = Rainfall depth (ft) for Treatment Volume

(Level 1 = 1" (0.08 ft); Level 2 = 1.1" (0.09 ft)) or other design storm

i = Field-verified infiltration rate for native soils (ft./day)

t_f = Time to fill reservoir layer (day) –2 hours or 0.083 day

V_r or η_r = Porosity (or void ratio) of reservoir layer (0.4)

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Permeable Pavement

VIRGINIA DEQ STORMWATER DESIGN SPECIFICATION No. 7

Key Design Consideration: Pavement Structural Design

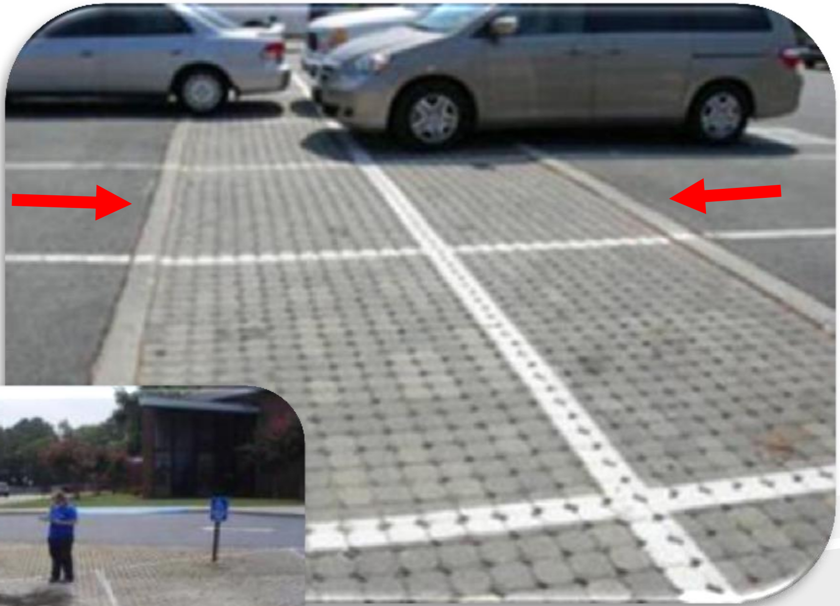
Thickness of permeable pavement and reservoir layer must be sized to support structural loads

Permeable Pavement

VIRGINIA DEQ STORMWATER DESIGN SPECIFICATION No. 7

Key Design Consideration: External Drainage Areas

- **The maximum external drainage area is limited to ratio with area of permeable pavement: 2:1**
- In all cases, external drainage areas should be limited to impervious surfaces to reduce potential sediment loading



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Permeable Pavement

VIRGINIA DEQ STORMWATER DESIGN SPECIFICATION No. 7

Four primary design elements:

- Anticipated traffic loads
- Underlying soil properties
- Environmental/climate factors
- Surface, bedding, and reservoir strength coefficients and layer thicknesses (strength coefficients vary for materials used)

Permeable Pavement

VIRGINIA DEQ STORMWATER DESIGN SPECIFICATION No. 7

Key Design Consideration: Construction

- Contractor Qualifications
- Material specifications

Permeable Pavement

VIRGINIA DEQ STORMWATER DESIGN SPECIFICATION No. 7

Key Design Consideration: Maintenance Agreements

Permeable Pavement (like all BMPs) must have maintenance agreement, and should include provisions for owner awareness of routine (frequent) and infrequent maintenance requirements.

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Infiltration Practices

VIRGINIA DEQ STORMWATER DESIGN SPECIFICATION No. 8

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Infiltration Practices

VIRGINIA DEQ STORMWATER DESIGN SPECIFICATION No. 8

Summary of Stormwater Functions [1]

Stormwater Function	Level 1 Design	Level 2 Design
Annual Runoff Volume Reduction (RR)	50%	90%
Total Phosphorus (TP) EMC Reduction[1] by BMP Treatment Process	25%	25%
Total Phosphorus (TP) Mass Load Removal	63%	93%
Total Nitrogen (TN) EMC Reduction[1] by BMP Treatment Process	15%	15%
Total Nitrogen (TN) Mass Load Removal	57%	92%
Channel and Flood Protection	• Use the Virginia Runoff Reduction Method (VRRM) Compliance Spreadsheet to calculate the Curve Number (CN) Adjustment ***OR*** • Design for extra storage (optional; as needed) on the surface or in the subsurface storage volume to accommodate larger storm volumes, and use NRCS TR-55 Runoff Equations [2] to compute the CN Adjustment.	

[1] Change in the event mean concentration (EMC) through the practice. The actual nutrient mass load removed is the product of the removal rate and the runoff reduction (RR) rate (see Table 1 in the *Introduction to the New Virginia Stormwater Design Specifications*).

[2] NRCS TR-55 Runoff Equations 2-1 thru 2-5 and Figure 2-1 can be used to compute a curve number adjustment for larger storm events, based on the retention storage provided by the practice(s).

Infiltration Practices

VIRGINIA DEQ STORMWATER DESIGN SPECIFICATION No. 8

Infiltration Practices Design Criteria

Level 1 Design (RR:50; TP:25; TN:15)	Level 2 Design (RR:90; TP:25; TN:15)
Sizing: T_V = [(Rv)(A)/12] + any remaining volume from upstream BMP(s)	Sizing: T_V = [1.1(Rv)(A)/12] + any remaining volume from upstream BMP(s)
At least two forms of pre-treatment (see **Table 8.6**)	At least three forms of pre-treatment (see **Table 8.6**)
Soil infiltration rate 1/2 to 1 in./hr. (see **Section 6.1** & **Appendix 8-A**); number of tests depends on the scale (**Table 8.4**)	Soil infiltration rates of 1.0 to 4.0 in/hr (see **Section 6.1** & **Appendix 8-A**); number of tests depends on the scale (**Table 8.4**)
Minimum of 2 feet between the bottom of the infiltration practice and the seasonal high water table or bedrock (**Section 5**)	
T_V infiltrates within 36 to 48 hours (**Section 6.6**)	
Building Setbacks – see **Table 8.4**	
All Designs are subject to hotspot runoff restrictions/prohibitions	

Virginia Department of Environmental Quality

Infiltration Practices

VIRGINIA DEQ STORMWATER DESIGN SPECIFICATION No. 8

Key Design Consideration: Applicability

- *Soils*
- Minimum depth to water table or bedrock
- Use on urban soils/redevelopment sites
- High loading situations
- Groundwater protection

Infiltration Practices

VIRGINIA DEQ STORMWATER DESIGN SPECIFICATION No. 8

Key Design Consideration: Pre-treatment

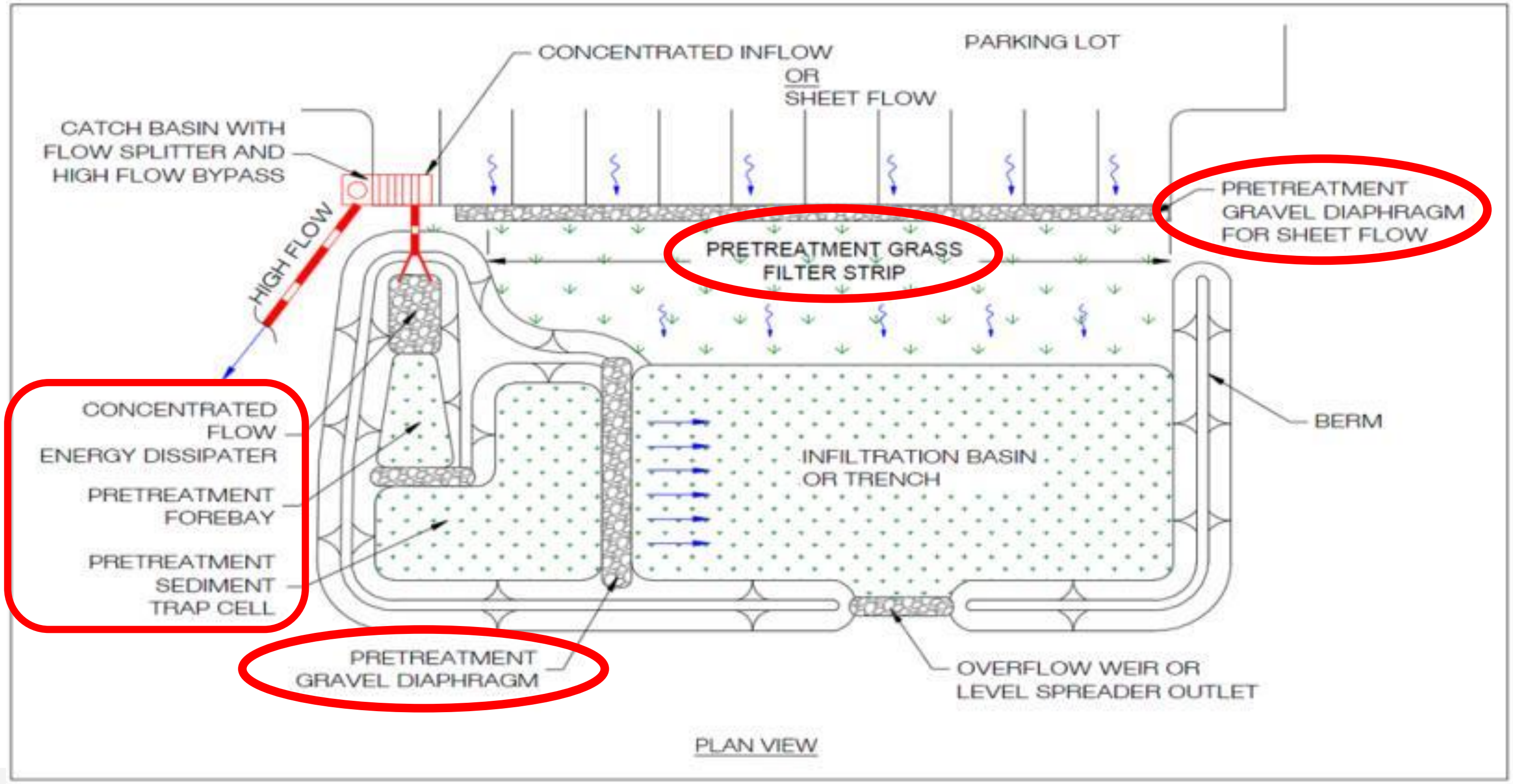

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Table 8.3. The Three Design Scales for Infiltration Practices

Design Factor	Micro-Infiltration	Small-Scale Infiltration	Conventional Infiltration
Impervious Area Treated	250 to 2,500 sq. ft.	2,500 to 20,000 sq. ft.	20,000 to 100,000 sq. ft.
Typical Practices	Dry Well French Drain Paving Blocks	Infiltration Trench Permeable Paving [1]	Infiltration Trench Infiltration Basin
Min.Infiltration Rate	1/2 inch/hour		
Design Infil. Rate	50% of measured rate		
Observation Well	No	Yes	Yes
Type of Pretreatment (see **Table 8.6**)	External (leaf screens, grass filter strip, etc)	Vegetated filter strip or grass channel, forebay, etc.	Pretreatment Cell
Depth Dimensions	Max. 3-foot depth	Max. 5-foot depth	Max. 6-foot depth,
UIC Permit Needed	No	No	Only if the surface width is less than the max. depth
Head Required	Nominal: 1 to 3 feet	Moderate: 1 to 5 feet	Moderate: 2 to 6 feet
Underdrain Requirements?	An elevated underdrain only on marginal soils	None required	Back up underdrain
Required Soil Tests	One per practice	One (1) per 1,000 sq. ft. of surface area or max. two (2) per practice.	One per 1,000 sq. ft. of surface area.
Building Setbacks	5 feet down-gradient [2] 25 feet up-gradient	10 feet down-gradient 50 feet up-gradient	25 feet down-gradient 100 feet up-gradient

[1] Although permeable pavement is an infiltration practice, a more detailed specification is provided in Stormwater Design Specification No. 7.

[2] Note that the building setback of 5 feet is intended for simple foundations. The use of a dry well or french drain adjacent to an in-ground basement or finished floor area should be carefully designed and coordinated with the design of the structure's water-proofing system (foundation drains, etc.), or avoided altogether.

Table 19. Required Pre-treatment Elements for Infiltration Practices

(From Spec. No. 8, Table 8.6, page 12)

Pre-treatment [1]	Scale of Infiltration		
	Micro Infiltration	**Small-Scale Infiltration**	**Conventional Infiltration**
Number and Volume of Pre-treatment Techniques Employed	**2** external techniques; no minimum pre-treatment volume required.	**3** techniques; **15%** minimum pre-treatment volume required (inclusive).	**3** techniques; **25%** minimum pre-treatment volume required (inclusive); at least **one** separate pre-treatment cell.
Acceptable Pre-treatment Techniques[1]	Leaf gutter screens Grass filter strip Upper sand layer Washed bank run gravel	Grass filter strip Grass channel Plunge pool Gravel diaphragm	Sediment trap cell Sand filter cell Sump pit Grass filter strip Gravel diaphragm

[1] A minimum of 50% of the runoff reduction volume must be pre-treated by a filtering or bioretention practice *prior* to infiltration *if* the site is a restricted stormwater hotspot

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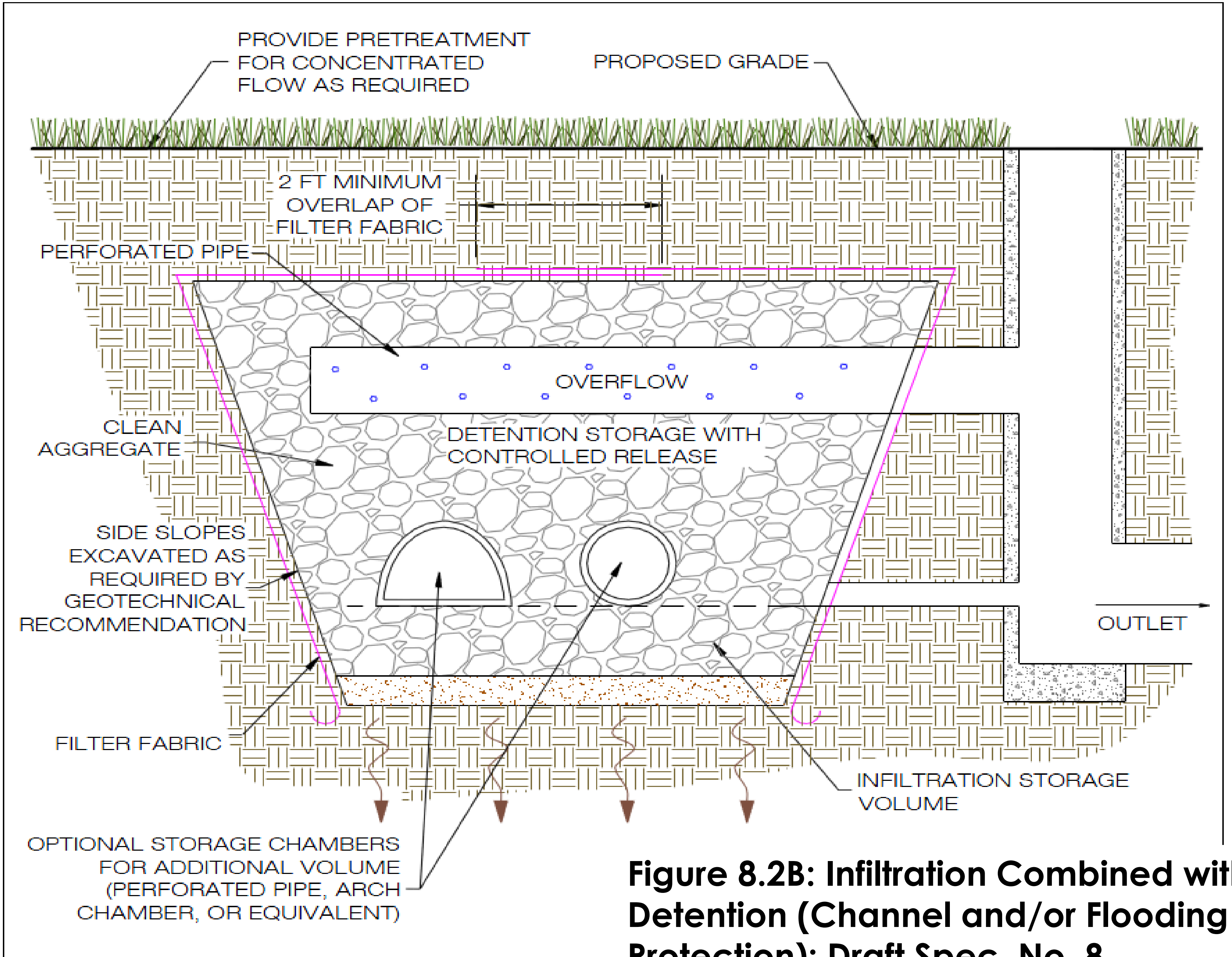

Figure 8.2B: Infiltration Combined with Detention (Channel and/or Flooding Protection); Draft Spec. No. 8

APPENDIX 8-A

INFILTRATION SOIL TESTING PROCEDURES

I. Test Pit/Boring Procedures

1. One (1) test pit or standard soil boring should be provided for every 1,000 square feet of the proposed infiltration area.

2. The location of each test pit or standard soil boring should correspond to the location of the proposed infiltration area.

3. Excavate each test pit or penetrate each standard soil boring to a depth at least 2 feet below the bottom of the proposed infiltration area.

4. If the groundwater table is located within 2 feet of the bottom of the proposed facility, determine the depth to the groundwater table immediately upon excavation and again 24 hours after excavation is completed.

5. Conduct Standard Penetration Testing (SPT) every 2 feet to a depth that is 2 feet below the bottom of the proposed infiltration area.

6. Determine the USDA or Unified Soil Classification system textures at the bottom of the proposed infiltration area and at a depth that is 2 feet below the bottom. All soil horizons should be classified and described.

7. If bedrock is located within 2 feet of the bottom of the proposed infiltration area, determine the depth to the bedrock layer.

8. Test pit/soil boring stakes should be left in the field to identify where soil investigations were performed.

II. Infiltration Testing Procedures

1. One infiltration test should be conducted for every 1,000 square feet of surface area for the infiltration area.

Bioretention

VIRGINIA DEQ STORMWATER DESIGN SPECIFICATION No. 9

VIRGINIA DEPARTMENT OF ENVIRONMENTAL QUALITY

Bioretention

VIRGINIA DEQ STORMWATER DESIGN SPECIFICATION No. 9

Summary of Stormwater Functions [1]

Stormwater Function	Level 1 Design	Level 2 Design
Annual Runoff Volume Reduction (RR)	40%	80%
Total Phosphorus (TP) EMC Reduction[1] by BMP Treatment Process	25%	50%
Total Phosphorus (TP) Mass Load Removal	55%	90%
Total Nitrogen (TN) EMC Reduction[1] by BMP Treatment Process	40%	60%
Total Nitrogen (TN) Mass Load Removal	64%	90%
Channel and Flood Protection	• Use the Virginia Runoff Reduction Method (VRRM) Compliance Spreadsheet to calculate the Curve Number (CN) Adjustment *OR* • Design extra storage (optional; as needed) on the surface, in the engineered soil matrix, and in the stone/underdrain layer to accommodate a larger storm, and use NRCS TR-55 Runoff Equations[2] to compute the CN Adjustment.	

[1] Change in event mean concentration (EMC) through the practice. Actual nutrient mass load removed is the product of the removal rate and the runoff reduction rate(see Table 1 in the *Introduction to the New Virginia Stormwater Design Specifications*).
[2] NRCS TR-55 Runoff Equations 2-1 thru 2-5 and Figure 2-1 can be used to compute a curve number adjustment for larger storm events based on the retention storage provided by the practice(s).

Sources: CWP and CSN (2008) and CWP (2007)

Bioretention

VIRGINIA DEQ STORMWATER DESIGN SPECIFICATION No. 9

Level 1 & 2 Bioretention Design Criteria:

- Micro-Bioretention (Raingardens) **Table 9.2*
- Bioretention **Table 9.3*

Urban Bioretention Design Criteria:

- Micro-Bioretention with provisions **Appendix 9-A*
  - Urban Planter boxes
  - Expanded Tree Pits
  - Curb Extensions

VIRGINIA DEPARTMENT OF ENVIRONMENTAL QUALITY

Bioretention

VIRGINIA DEQ STORMWATER DESIGN SPECIFICATION No. 9

Testing of underlying native soils:

Level 1

- If no underdrain used

Level 2

- Always

even if underdrain used

See Appendix 8-A

Bioretention

VIRGINIA DEQ STORMWATER DESIGN SPECIFICATION No. 9

Micro-Bioretention Design Criteria

Level 1 Design (RR 40 TP: 25)	Level 2 Design (RR: 80 TP: 50)
Sizing: Filter surface area (sq. ft.) = 3% [2] of the contributing drainage area (CDA).	Sizing: Filter surface area (sq. ft.) = 4% [2] of the CDA (can be divided into different cells at downspouts).
Maximum contributing drainage area = 0.5 acres; 25% Impervious Cover (IC) [2]	
One cell design (can be divided into smaller cells at downspout locations) [2]	
Maximum Ponding Depth = 6 inches	
Filter Media Depth minimum = 18 inches; Recommended maximum = 36 inches	Filter Media Depth minimum = 24 inches; Recommended maximum = 36 inches
Media: mixed on-site or supplied by vendor	Media: supplied by vendor
All Designs: Media mix tested for an acceptable phosphorus index (P-Index) of between 10 and 30, ***OR*** Between 7 and 23 mg/kg of P in the soil media	
Sub-soil testing: not needed if an underdrain is used; Min infiltration rate > 1 inch/hour in order to remove the underdrain requirement.	Sub-soil testing: one per practice; Min infiltration rate > 1/2 inch/hour; Min infiltration rate > 1 inch/hour in order to remove the underdrain requirement.
Underdrain: corrugated HDPE or equivalent.	Underdrain: corrugated HDPE or equivalent, with a minimum 6-inch stone sump below the invert; ***OR*** none, if soil infiltration requirements are met
Clean-outs: not needed	
Inflow: sheetflow or roof leader	
Pretreatment: external (leaf screens, grass filter strip, energy dissipater, etc.).	Pretreatment: external *plus* a grass filter strip
Vegetation: turf, herbaceous, or shrubs (min = 1 out of those 3 choices).	Vegetation: turf, herbaceous, shrubs, or trees (min = 2 out of those 4 choices).
Building setbacks: 10 feet down-gradient; 25 feet up-gradient	

[1] Consult **Appendix 9-A** for design criteria for Urban Bioretention Practices.

[2] Micro-Bioretention (Rain Gardens) can be located at individual downspout locations to treat up to 1,000 sq. ft. of impervious cover (100% IC); the surface area is sized as 5% of the roof area (Level 1) or 6% of the roof area (Level 2), with the remaining Level 1 and Level 2 design criteria as provided in **Table 9.2**. If the Rain Garden is located so as to capture multiple rooftops, driveways, and adjacent pervious areas, the sizing rules within **Table 9.2** should apply.

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Virginia Department of Environmental Quality

Bioretention

VIRGINIA DEQ STORMWATER DESIGN SPECIFICATION No. 9

Key Design Consideration:

Micro-Bioretention

- Sizing based on simple surface area as % of CDA (not Tv_{BMP})
- New (20xx) specs modified so ‘micro’ and ‘urban’ consistent to avoid ‘cherry picking’ smaller design for relative scale of applications
- Level 1 & Level 2 Designs

VIRGINIA DEPARTMENT OF ENVIRONMENTAL QUALITY

Bioretention

VIRGINIA DEQ STORMWATER DESIGN SPECIFICATION No. 9

Bioretention Design Criteria

Level 1 Design (RR 40 TP: 25)	Level 2 Design (RR: 80 TP: 50)
Sizing (**Section 6.1**): *Tv_{BMP}* = [(1)(Rv)(A) / 12] + any remaining volume from upstream BMP Surface Area (sq. ft.) = *Tv_{BMP}* / Storage Depth [1]	Sizing (**Section 6.1**): *Tv_{BMP}* = [(1.25)(Rv)(A) / 12] + any remaining volume from upstream BMP Surface Area (sq. ft.) = *Tv_{BMP}* /Storage Depth [1]
Recommended maximum contributing drainage area = 2.5 acres	
Maximum Ponding Depth = 6 to 12 inches [2]	Maximum Ponding Depth = 6 to 12 inches [2]
Filter Media Depth minimum = 24 inches; recommended maximum = 6 feet	Filter Media Depth minimum = 36 inches; recommended maximum = 6 feet
Media & Surface Cover (**Section 6.6**) = supplied by vendor; tested for acceptable phosphorus index (P-Index) of between 10 and 30, *OR* Between 7 and 23 mg/kg of P in the soil media	
Sub-soil Testing (**Section 6.2**): not needed if an underdrain used; Min infiltration rate > 1/2 inch/hour in order to remove the underdrain requirement.	Sub-soil Testing (**Section 6.2**): one per 1,000 sq. ft. of filter surface; Min infiltration rate > 1/2 inch/hour in order to remove the underdrain requirement.
Underdrain (**Section 6.7**) = Schedule 40 PVC with clean-outs	Underdrain & Underground Storage Layer (**Section 6.7**) = Schedule 40 PVC with clean outs, and a minimum 12-inch stone sump below the invert; *OR*, none, if soil infiltration requirements are met (**Section 6.2**)
Inflow: sheetflow, curb cuts, trench drains, concentrated flow, or the equivalent	
Geometry (**Section 6.3**): Length of shortest flow path/Overall length = 0.3; *OR*, other design methods used to prevent short-circuiting; a one-cell design (not including the pre-treatment cell).	Geometry (**Section 6.3**): Length of shortest flow path/Overall length = 0.8; *OR*, other design methods used to prevent short-circuiting; a two-cell design (not including the pretreatment cell).
Pre-treatment (**Section 6.4**): a pretreatment cell, grass filter strip, gravel diaphragm, gravel flow spreader, or another approved (manufactured) pre-treatment structure.	Pre-treatment (**Section 6.4**): a pretreatment cell *plus* one of the following: a grass filter strip, gravel diaphragm, gravel flow spreader, or another approved (manufactured) pre-treatment structure.
Conveyance & Overflow (**Section 6.5**)	Conveyance & Overflow (**Section 6.5**)
Planting Plan (**Section 6.8**): a planting template to include turf, herbaceous vegetation, shrubs, and/or trees to achieve surface area coverage of at least 75% within 2 years.	Planting Plan (**Section 6.8**): a planting template to include turf, herbaceous vegetation, shrubs, and/or trees to achieve surface area coverage of at least 90% within 2 years. If using turf, must combine with other types of vegetation [1].
Building Setbacks [3] (**Section 5**): 0 to 0.5 acre CDA = 10 feet if down-gradient from building or level (coastal plain); 50 feet if up-gradient. 0.5 to 2.5 acre CDA = 25 feet if down-gradient from building or level (coastal plain); 100 feet if up-gradient. (Refer to additional setback criteria in **Section 5**)	
Deeded Maintenance O&M Plan (**Section 8**)	

[1] Storage depth is the sum of the Void Ratio (Vr) of the soil media and gravel layers multiplied by their respective depths, plus the surface ponding depth. Refer to **Section 6.1**.

[2] A ponding depth of 6 inches is preferred. Ponding depths greater than 6 inches will require a specific planting plan to ensure appropriate plant selection (**Section 6.8**).

[3] These are recommendations for simple building foundations. If an in-ground basement or other special conditions exist, the design should be reviewed by a licensed engineer. Also, a special footing or drainage design may be used to justify a reduction of the setbacks noted above.

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Bioretention

VIRGINIA DEQ STORMWATER DESIGN SPECIFICATION No. 9

Key Design Consideration: **Bioretention**

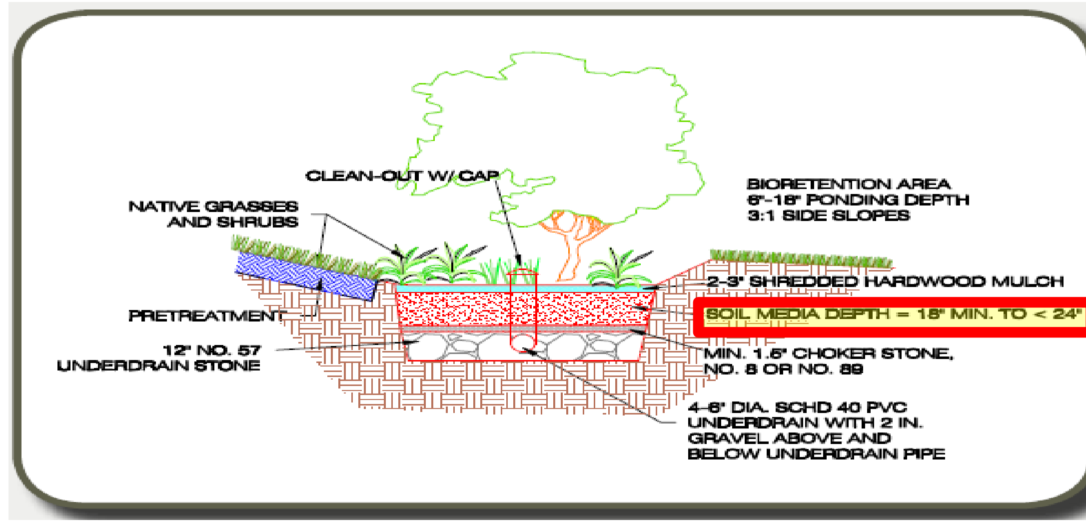
- Applications
- Sizing based on Tv_{BMP} (not simple surface area sizing based on % of CDA)

Bioretention

VIRGINIA DEQ STORMWATER DESIGN SPECIFICATION No. 9

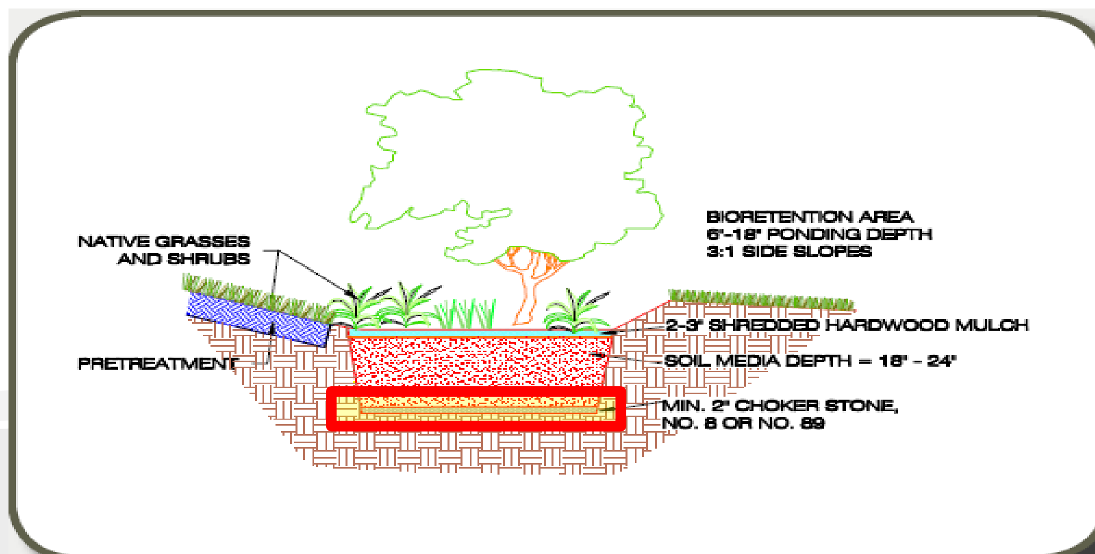
Level 1:

- Soil depth > 24”
- Underdrain
- Pretreatment



Level 2:

- Infiltration
- Soil depth > 36”
- Pretreatment (**+**)

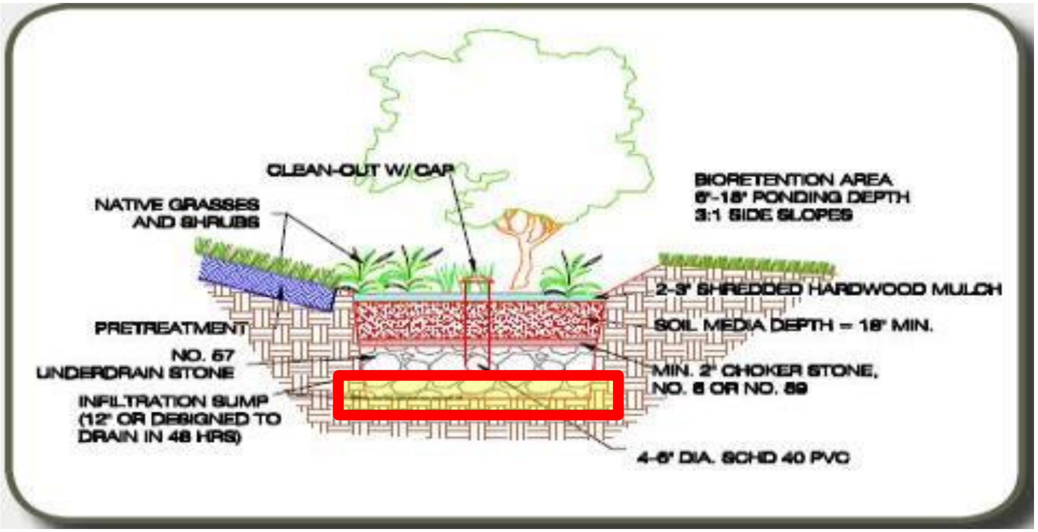


Bioretention

VIRGINIA DEQ STORMWATER DESIGN SPECIFICATION No. 9

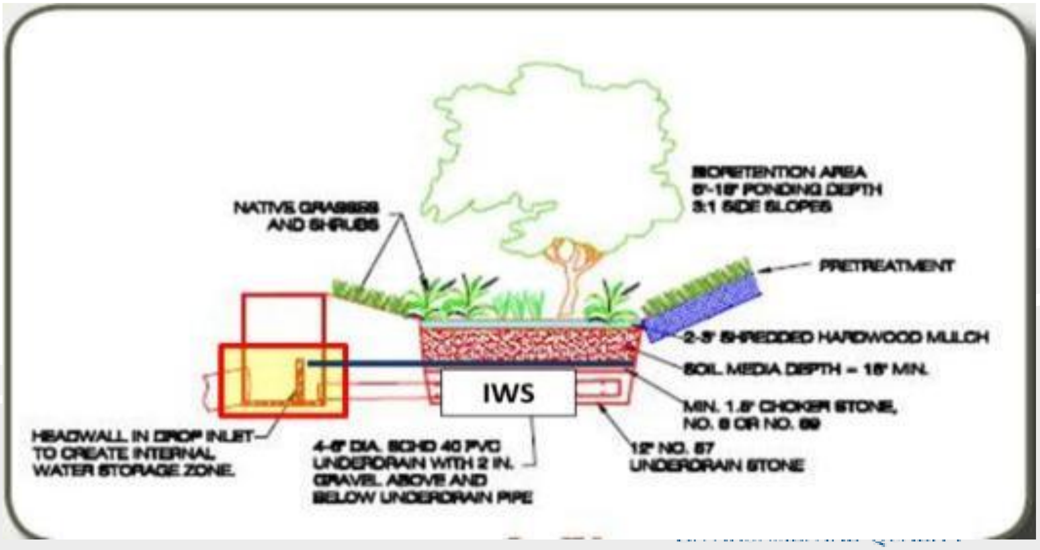
Level 2:

- Infiltration Sump



Level 2:

- Infiltration Sump with Internal Water Storage (IWS)



Bioretention

VIRGINIA DEQ STORMWATER DESIGN SPECIFICATION No. 9

Key Design Consideration: **Sizing**

Sizing of Bioretention based on capturing Tv_{BMP} within combined storage of surface ponding, soil media, and gravel (sump or under drain reservoir)

Accepted porosity (η) for each of materials is:

- Bioretention Soil Media η = 0.25
- Gravel η = 0.40
- Surface Storage η = 1.0

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Bioretention

VIRGINIA DEQ STORMWATER DESIGN SPECIFICATION No. 9

Key Design Consideration: **Sizing**

Level 1: Equivalent storage depth for Level 1 with 6-inch surface ponding depth, 24-inch soil media depth, and 12-inch gravel layer computed as:

$$(2\ ft.\ x\ 0.25) + (1\ ft.\ x\ 0.40) + (0.5\ x\ 1.0) = 1.40\ ft.$$

Corresponding surface area (SA) computed as:

$$SA\ (sq.\ ft.) = Tv_{BMP} / 1.40\ ft.$$

Tv_{BMP} = ***Level 1 BMP design treatment volume (cf)***

$= 1.25\ [(1.0\ in.)(R_v)(A) / 12]$

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Bioretention

VIRGINIA DEQ STORMWATER DESIGN SPECIFICATION No. 9

Key Design Consideration: **Sizing**

Level 2: Equivalent storage depth for Level 1 with 6-inch surface ponding depth, 24-inch soil media depth, and 12-inch gravel layer computed as:

$$(3 \text{ ft.} \times 0.25) + (1 \text{ ft.} \times 0.40) + (0.5 \times 1.0) = 1.65 \text{ ft.}$$

Corresponding surface area (SA) computed as:

$$SA \text{ (sq. ft.)} = Tv_{BMP} / 1.65 \text{ ft.}$$

Tv_{BMP} = *Level 1 BMP design treatment volume (cf)*

$$= 1.25\,[(1.0 \text{ in.})(R_v)(A) / 12]$$

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Bioretention

VIRGINIA DEQ STORMWATER DESIGN SPECIFICATION No. 9

Key Design Consideration: Surface Ponding

- Limits on increasing area of surface storage

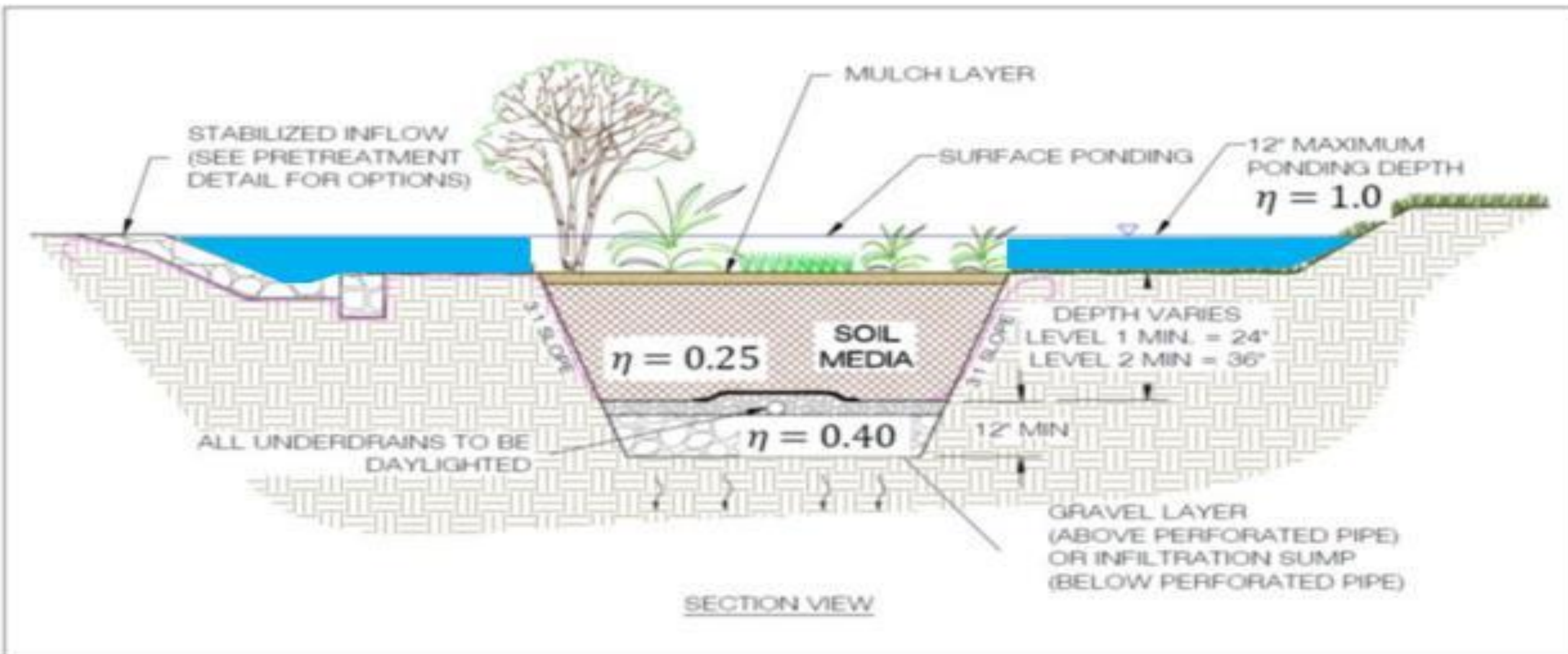
Bioretention

VIRGINIA DEQ STORMWATER DESIGN SPECIFICATION No. 9

Key Design Consideration: Surface Ponding

Limits on increasing area of surface storage

- ≤ 50% increase if ponding is 6” or less
- ≤ 25% increase if ponding is between 6 and 12”



Bioretention

VIRGINIA DEQ STORMWATER DESIGN SPECIFICATION No. 9

Key Design Consideration: Geometry & Flow Path

Bioretention

VIRGINIA DEQ STORMWATER DESIGN SPECIFICATION No. 9

Key Design Consideration: Inflow

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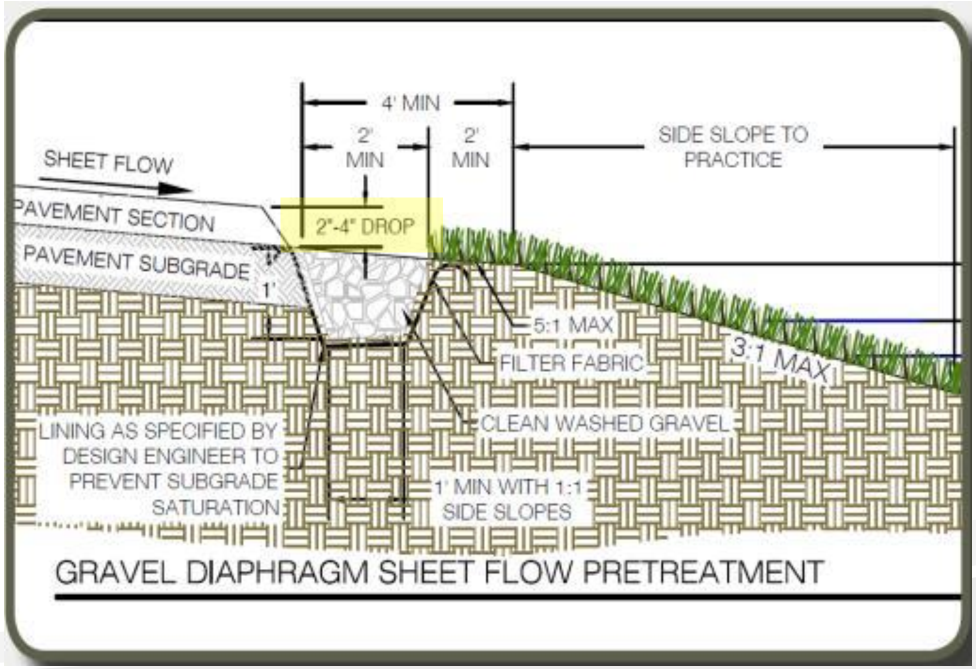
Bioretention

VIRGINIA DEQ STORMWATER DESIGN SPECIFICATION No. 9

Key Design Consideration: Pre-treatment

- Level 2: two pretreatment features required



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Bioretention

VIRGINIA DEQ STORMWATER DESIGN SPECIFICATION No. 9

Key Design Consideration: Media Components

- Soil media
- Choker stone (no filter fabric!)
- Underdrains

Bioretention

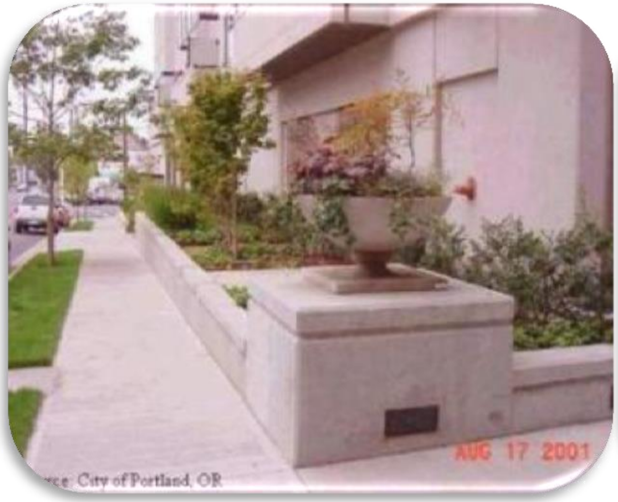
VIRGINIA DEQ STORMWATER DESIGN SPECIFICATION No. 9

Key Design Consideration: Vegetation

Bioretention

VIRGINIA DEQ STORMWATER DESIGN SPECIFICATION No. 9

Urban Bioretention



Urban Planters

Expanded Tree Box

Curb Extensions

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Bioretention

VIRGINIA DEQ STORMWATER DESIGN SPECIFICATION No. 9

Urban-Bioretention Design Criteria

Level 1 Design Only (RR: 40; TP: 25)
Sizing (Refer to **Section 9-A-6.1**): Surface Area (sq. ft.) = $T_v/2$ = {[(1.0 inch)(R_v)(A)/12)] + any remaining volume from upstream BMP }/2
Underdrain = Schedule 40 PVC with clean-outs (Refer to the Main Bioretention Design Specification, **Section 6.7**)
Maximum Drainage Area = 2,500 sq. ft.
Maximum Ponding Depth = 6 to 12 inches [1]
Filter media depth minimum = 30 inches; recommended maximum = 48 inches
Media and Surface Cover (Refer to the Main Bioretention Design Specification, **Section 6.6**)
Sub-soil testing (Refer to the Main Bioretention Design Specification, **Section 6.2**)
Inflow = sheetflow, curb cuts, trench drains, roof drains, concentrated flow, or equivalent
Building setbacks (Refer to **Section A-4 9-A-5**)
Deeded maintenance O&M plan (Refer to the Main Bioretention Design Specification, **Section 9.1**)
[1] Ponding depth above 6 inches will require a specific planting plan to ensure appropriate plants (Refer to the Main Bioretention Design Specification, **Section 6.1**).

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Dry Swale

VIRGINIA DEQ STORMWATER DESIGN SPECIFICATION No. 10

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Table 25: Summary of Stormwater Functions Provided by Dry Swale
(From Spec. No. 10, Table 10.1, page 2)

Stormwater Function	Level 1 Design	Level 2 Design
Annual Runoff Volume Reduction (RR)	40%	60%
Total Phosphorus (TP) EMC Reduction[1] by BMP Treatment Process	20%	40%
Total Phosphorus (TP) Mass Load Removal	52%	76%
Total Nitrogen (TN) EMC Reduction[1] by BMP Treatment Process	25%	35%
Total Nitrogen (TN) Mass Load Removal	55%	74%
Channel Protection	Use the Virginia Runoff reduction Method (VRRM) Compliance Spreadsheet to calculate the Curve Number (CN) Adjustment ***OR*** Design for extra storage (optional; as needed) on the surface, in the engineered soil matrix, and in the stone/underdrain layer to accommodate a larger storm, and use NRCS TR-55 Runoff Equations[2] to compute the CN Adjustment.	
Flood Mitigation	Partial. Reduced Curve Numbers and Time of Concentration	

[1] Change in the event mean concentration (EMC) through the practice. The actual nutrient mass load removed is the product of the removal rate and the runoff reduction rate (see Table 1 in the *Introduction to the New Virginia Stormwater Design Specifications*).
[2] NRCS TR-55 Runoff Equations 2-1 thru 2-5 and Figure 2-1 can be used to compute a curve number adjustment for larger storm events, based on the retention storage provided by the practice(s).

Table 26. Dry Swale Design Criteria
(From Spec. No. 10, Table 10.2, page 3)

Level 1 Design (RR:40; TP:20; TN:25)	Level 2 Design (RR:60; TP:40; TN: 35)
<u>Sizing (**Sec. 6.1**):</u> Tv_{BMP} = [(**1**)(Rv)(A) / 12] + any remaining volume from upstream BMP Surface Area (sq. ft.) = Tv_{BMP} / Storage depth [1]	<u>Sizing (**Sec. 6.1**):</u> Tv_{BMP} = [(**1.1**)(Rv)(A) / 12] + any remaining volume from upstream BMP Surface Area sq. ft.) = Tv_{BMP} / Storage Depth [1]
Effective swale slope ≤ 2%[2]	Effective swale slope ≤ 1%[2]
<u>Media Depth</u>: minimum = **18 inches**; Recommended maximum = 36 inches	<u>Media Depth</u> minimum = **24 inches** Recommended maximum = 36 inches
<u>Sub-soil testing (**Section 6.2**)</u>: not needed if an underdrain is used; min. infiltration rate must be > 1/2 inch/hour to remove the underdrain requirement;	<u>Sub-soil testing (**Section 6.2**)</u>: one per 200 linear feet of filter surface; min. infiltration rate must be > 1/2 inch/hour to remove the underdrain requirement
<u>Underdrain (**Section 6.7**)</u>: Schedule 40 PVC with clean-outs	<u>Underdrain and Underground Storage Layer (**Section 6.7**)</u>: Schedule 40 PVC with clean outs, and a minimum 12-inch stone sump below the invert; ***OR*** none if the soil infiltration requirements are met (see <u>**Section 6.2**</u>)

Table 26. Dry Swale Design Criteria (Continued)

(From Spec. No. 10, Table 10.2, page 3)

Level 1 Design (RR:40; TP:20; TN:25)	Level 2 Design (RR:60; TP:40; TN: 35)
Media (**Section 6.6**): supplied by the vendor; tested for an acceptable hydraulic conductivity (or permeability) and phosphorus content [3]	
Inflow: sheet or concentrated flow with appropriate pre-treatment	
Pre-Treatment (**Section 6.4**): a pretreatment cell, grass filter strip, gravel diaphragm, gravel flow spreader, or another approved (manufactured) pre-treatment structure.	
On-line design	Off-line design or multiple treatment cells
Turf cover	Turf cover, with trees and shrubs
Building Setbacks [4] (**Section 5**): 10 feet if down-gradient from building or level (coastal plain); 50 feet if up-gradient. (Refer to additional setback criteria in **Section 5**)	

[1] Storage depth is sum of porosity (η) of soil media and gravel layers multiplied by their respective depths, plus surface ponding depth (Refer to **Section 6.1**)

[2] Effective swale slope can be achieved through use of check dams – 12-inch height maximum

[3] Refer to Stormwater Design Specification No. 9: Bioretention for soil specifications

[4] These are recommendations for simple building foundations. If in-ground basement or other special conditions exist, design should be reviewed by licensed engineer. Also, special footing or drainage design may be used to justify reduction of setbacks noted above.

Wet Swale

VIRGINIA DEQ STORMWATER DESIGN SPECIFICATION No. 11

Virginia Department of Environmental Quality

Table 27: Summary of Stormwater Functions Provided by Wet Swale Practices
(From Spec. No. 11, Table 11.1, page 2)

Stormwater Function	Level 1 Design	Level 2 Design
Annual Runoff Volume Reduction (RR)	0%	0%
Total Phosphorus (TP) EMC Reduction[1] by BMP Treatment Process	20%	40%
Total Phosphorus (TP) Mass Load Removal	20%	40%
Total Nitrogen (TN) EMC Reduction[1] by BMP Treatment Process	25%	35%
Total Nitrogen (TN) Mass Load Removal	25%	35%
Channel Protection	Limited – reduced Time of Concentration; and partial detention volume can be provided above the Treatment Volume (*Tv*), within the allowable maximum ponding depth.	
Flood Mitigation	Limited	
[1] Change in event mean concentration (EMC) through the practice.		

Table 28. Wet Swale Design Criteria

(From Spec. No. 11, Table 11.2, page 2)

Level 1 Design (RR:0; TP:20; TN:25)	Level 2 Design (RR:0; TP:40; TN:35)
Tv_{BMP} = [(1.0)(R_V)(A)] / 12 + any remaining volume from upstream BMP(s)	Tv_{BMP} = [(1.25)(R_V)(A)] / 12 + any remaining volume from an upstream BMP(s)
Swale slopes less than 2% [1]	Swale slopes less than 1% [1]
On-line design	Off-line swale cells
Minimal planting; volunteer vegetation	Wetland planting within swale cells
Turf cover in buffer	Trees, shrubs, and/or ground cover within swale cells and buffer

[1] Wet Swales are generally recommended only for flat coastal plain conditions with a high water table. A linear wetland is always preferred to a wet swale. However, check dams or other design features that lower the effective longitudinal grade of the swale can be applied on steeper sites, to comply with these criteria.

Filtering Practices

VIRGINIA DEQ STORMWATER DESIGN SPECIFICATION No. 12

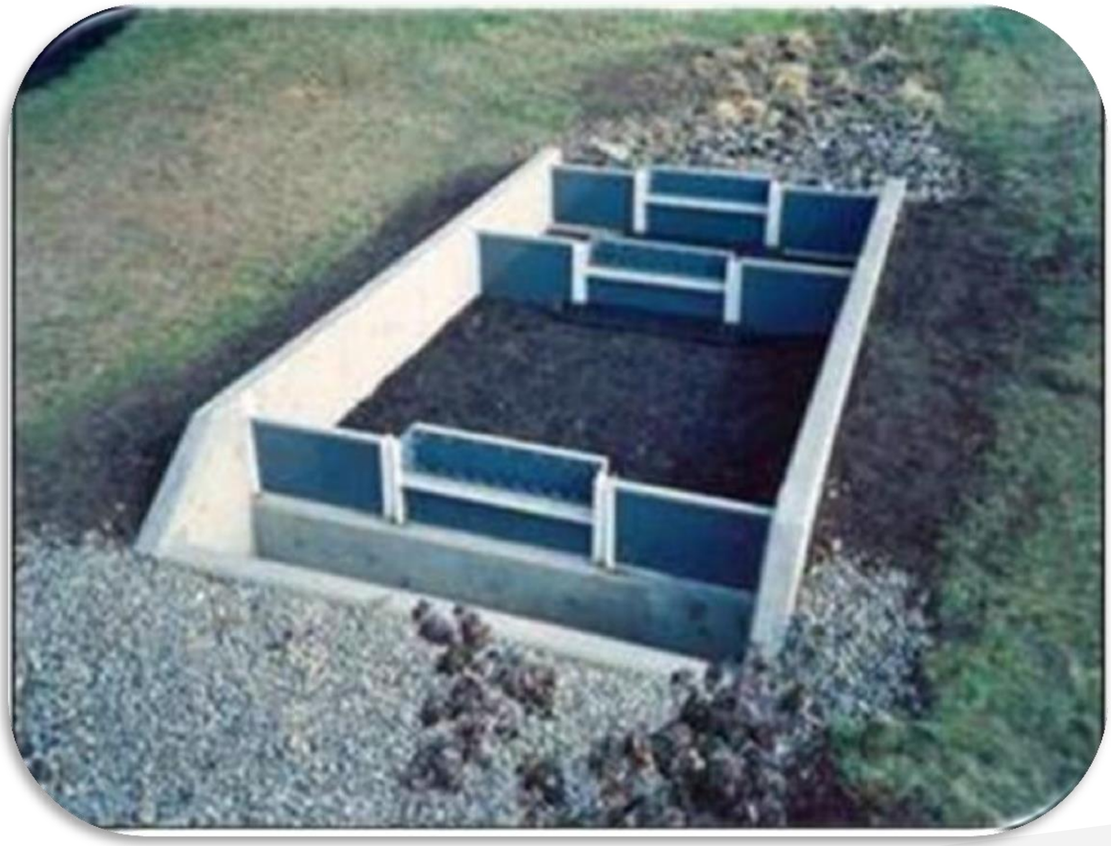

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Table 29: Summary of Stormwater Functions Provided by Filtering Practices
(From Spec. No. 12, Table 12.1, page 2)

Stormwater Function	Level 1 Design	Level 2 Design
Annual Runoff Volume Reduction (RR)	0%	0%
Total Phosphorus (TP) EMC Reduction[1] by BMP Treatment Process	60%	65%
Total Phosphorus (TP) Mass Load Removal	60%	65%
Total Nitrogen (TN) EMC Reduction[1] by BMP Treatment Process	30%	45%
Total Nitrogen (TN) Mass Load Removal	30%	45%
Channel Protection	Limited – Runoff diverted off-line into a storage facility for treatment can be supplemented with an outlet control to provide peak rate control.	
Flood Mitigation	None. Most filtering practices are off-line and do not materially change peak discharges.	
[1] Change in the event mean concentration (EMC) through the practice..		

Table 30. Filtering Practice Design Criteria
(From Spec. No. 12, Table 12.2, page 2)

Level 1 Design (RR:0; TP:60; TN:30)	Level 2 Design (RR:0 [1]; TP:65; TN:45)
Tv = [(1.0)(Rv)(A)] / 12 + any remaining volume from upstream BMP(s)	Tv = [(1.25)(Rv)(A)] / 12 + any remaining volume from upstream BMP(s)
One cell design[2]	Two cell design[2]
Sand media	Sand media with an organic layer
Contributing Drainage Area (CDA) contains pervious area	CDA is nearly 100% impervious

[1] May be increased if the 2nd cell is utilized for infiltration in accordance with Stormwater Design Specification No. 8 (Infiltration) or Stormwater Design Specification No. 9 (Bioretention). The Runoff Reduction (RR) credit should be proportional to the fraction of the Tv designed to be infiltrated.

[2] A pretreatment sedimentation chamber or forebay is not considered a separate cell

Constructed Wetlands

VIRGINIA DEQ STORMWATER DESIGN SPECIFICATION No. 13

Table 31: Summary of Stormwater Functions Provided by Constructed Wetlands

(From Spec. No. 13, Table 13.1, page 2)

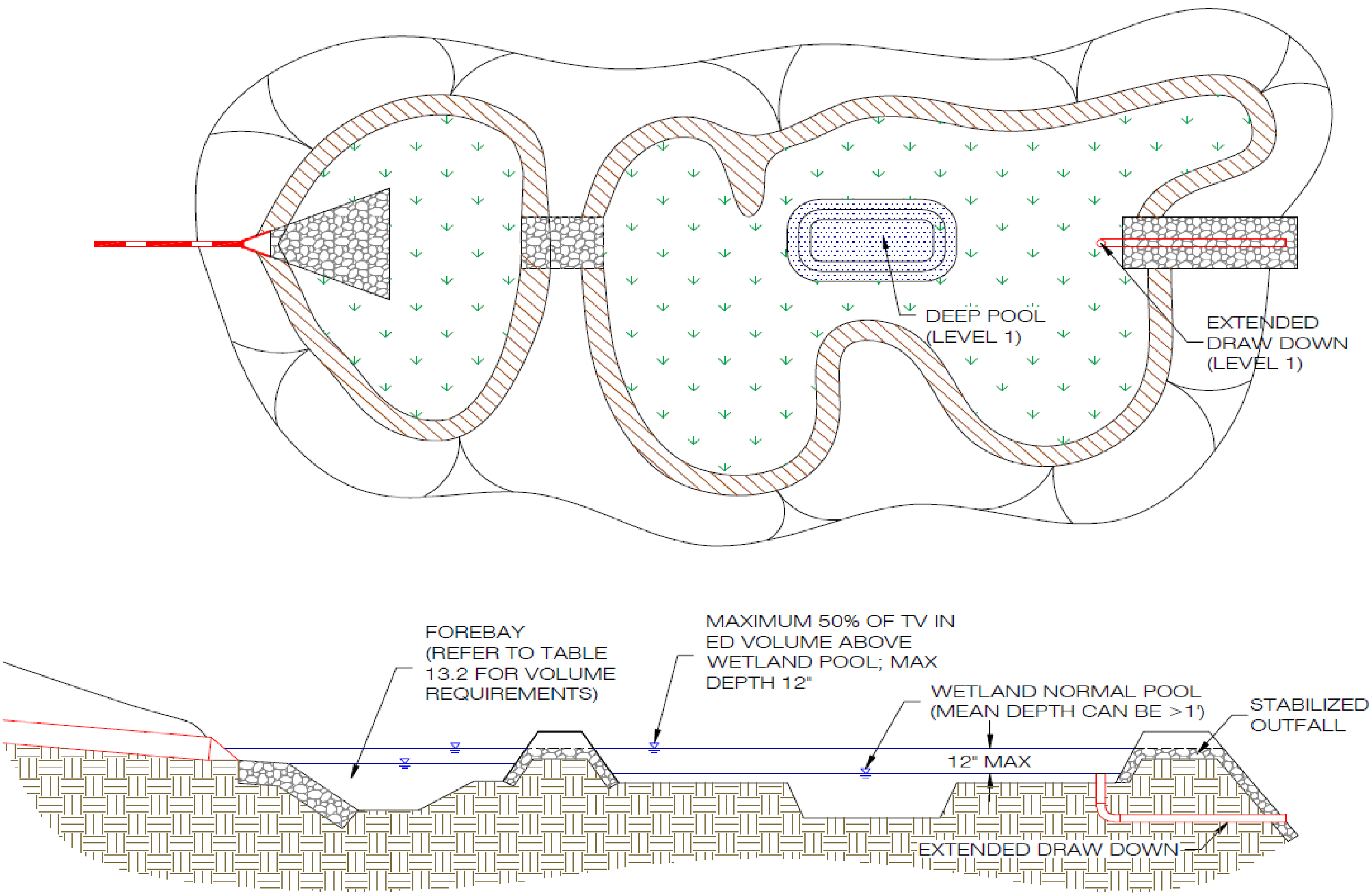
Stormwater Function	Level 1 Design	Level 2 Design
Annual Runoff Volume Reduction (RR)	0%	0%
Total Phosphorus (TP) EMC Reduction[1] by BMP Treatment Process	50%	75%
Total Phosphorus (TP) Mass Load Removal	50%	75%
Total Nitrogen (TN) EMC Reduction[1] by BMP Treatment Process	25%	55%
Total Nitrogen (TN) Mass Load Removal	25%	55%
Channel Protection	Yes. Up to 1 foot of detention storage volume can be provided above the normal pool.	
Flood Mitigation	Yes. Flood control storage can be provided above the normal pool.	
[1] Change in event mean concentration (EMC) through the practice.		

Table 32. Constructed Wetlands Design Criteria
(From Spec. No. 13, Table 13.2, page 3)

Level 1 Design (RR:0; TP:50; TN:25)	Level 2 Design (RR:0; TP:75; TN:55)
Tv_{BMP} = [(1.0)(R_V)(A)] / 12 + any remaining volume from upstream BMP(s)	Tv_{BMP} = [(1.5)(R_V)(A)] / 12 + any remaining volume from upstream BMP(s)
Single cell (with a forebay and micropool outlet)[1,2] **Section 6.5**	Multiple cells or a multi-cell pond/wetland combination[1,2] **Sections 6.2 and 6.5**
Extended Detention (ED) for 50% of Tv (24 hr)[3] or Detention storage (up to 12 inches) above the wetland pool for channel protection (1-year storm event); **Section 6.2**	No ED or detention storage. (limited water surface fluctuations allowed during the 1-inch and 1-year storm events; **Section 6.2)**
Uniform wetland depth [2] Allowable mean wetland depth is > than 1 foot; **Section 6.2**	Diverse microtopography with varying depths [2]**;** Allowable mean wetland depth ≤1 foot; **Section 6.2**
The surface area of the wetland is *less* than 3% of the contributing drainage area (CDA); **Section 6.2**.	The surface area of the wetland is *more* than 3% of the CDA; **Section 6.2**
Length/Width ratio *OR* Flow path = 2:1 or more Length of shortest flow path/overall length = 0.5 or more [3] **Section 6.3**	Length/Width ratio *OR* Flow path = 3:1 or more Length of shortest flow path/overall length = 0.8 or more [4] **Section 6.3**
Emergent wetland design, **Section 6.7**	Emergent and Upland wetland design, **Section 6.7**

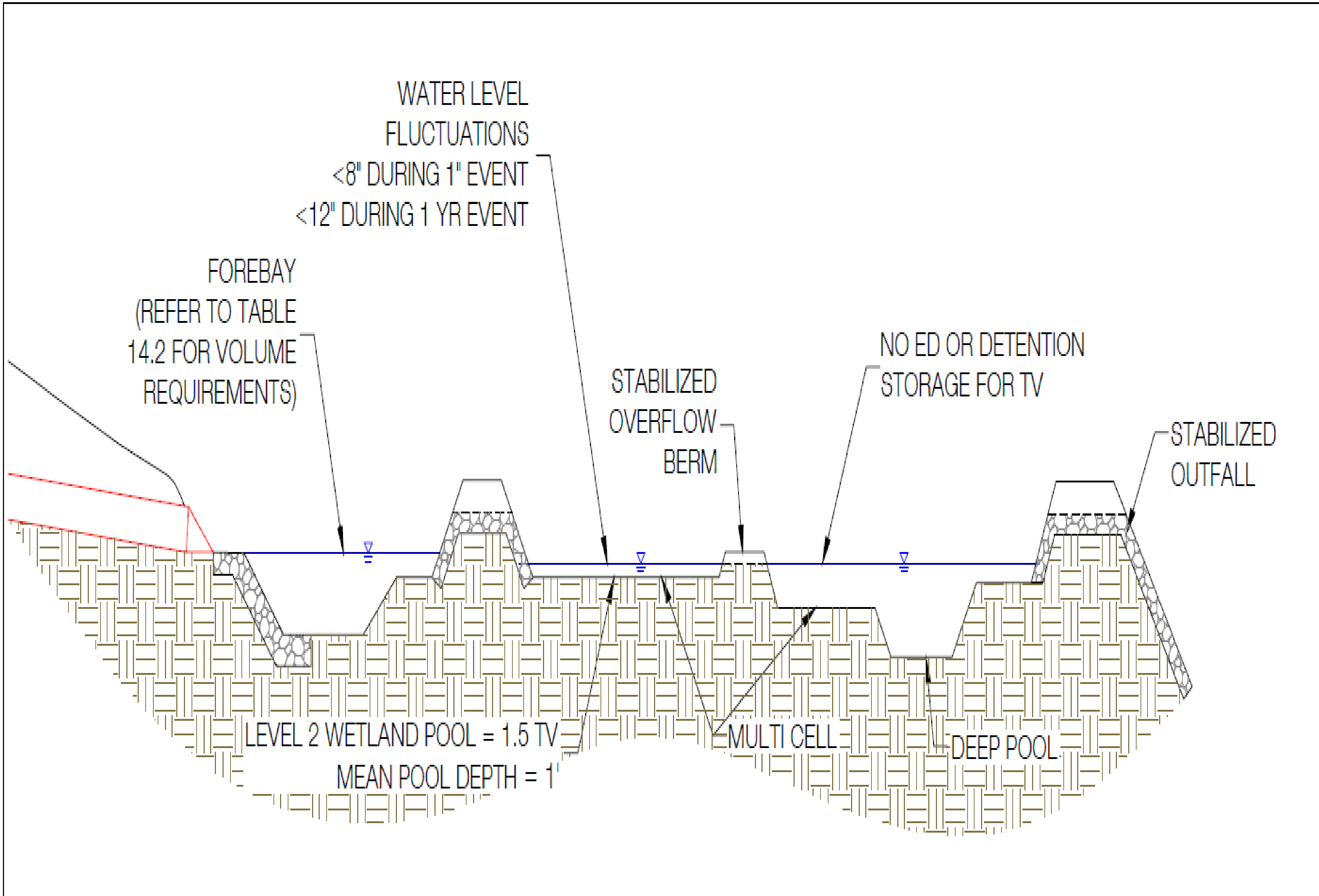
[1] Pre-treatment Forebay required – refer to **Section 6.5**
[2] Internal Tv storage volume geometry – refer to **Section 6.6**
[3] Extended Detention may be provided to meet a maximum of 50% of the Treatment Volume; Refer to Design Specification 15 for ED design – refer to **Section 6.2**
[4] In the case of multiple inlets, the flow path is measured from the dominant inlets (that comprise 80% or more of the total pond inflow), **Section 6.3**

Level 1 Constructed Wetland Plan and Cross Section

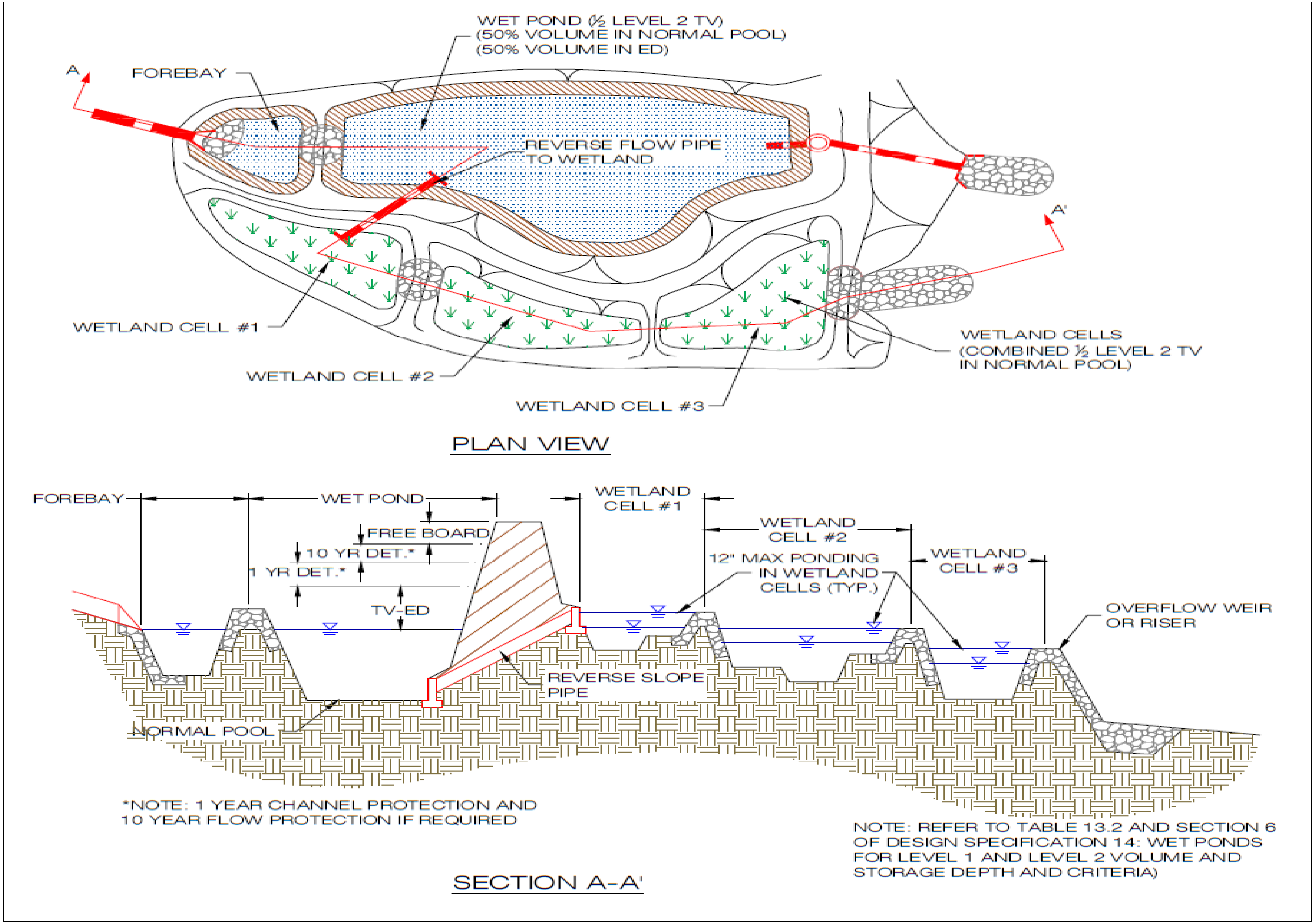


CONSTRUCTED WETLAND BASIN - LEVEL 1
PLAN AND PROFILE

Level 2 Constructed Wetland Cross Section



Constructed Wetland Level 2 – Pond-Wetland Combination



Wet Ponds

VIRGINIA DEQ STORMWATER DESIGN SPECIFICATION No. 14

VIRGINIA DEPARTMENT OF ENVIRONMENTAL QUALITY

Table 33: Summary of Stormwater Functions Provided by Wet Ponds
(From Spec. No. 14 Table 14.1, page 2)

Stormwater Function	Level 1 Design	Level 2 Design
Annual Runoff Volume Reduction (RR) [1]	0%	0%
Total Phosphorus (TP) EMC Reduction[2] **by BMP Treatment Process**	50% (45%) [3]	75% (65%) [3]
Total Phosphorus (TP) Mass Load Removal	50% (45%) [3]	75% (65%) [3]
Total Nitrogen (TN) EMC Reduction[2] **by BMP Treatment Process**	30% (20%) [3]	40% (30%) [3]
Total Nitrogen (TN) Mass Load Removal	30% (20%) [3]	40% (30%) [3]
Channel Protection	Yes; detention storage can be provided above the permanent pool.	
Flood Mitigation	Yes; flood control storage can be provided above the permanent pool.	

[1] Runoff Reduction rates for ponds used for year round irrigation can be determined through a water budget computation.
[2] Change in event mean concentration (EMC) through the practice.
[3] Number in parentheses is slightly lower EMC removal rate in the coastal plain (or any location) if the wet pond is influenced by groundwater. See **Section 6.2** of this design specification and CSN Technical Bulletin No. 2. (2009).

Table 34. Wet Pond Design Guidance

(From Spec. No. 14, Table 14.2, page 3)

Level 1 Design (RR:0 [1]; TP: 50 [5]; TN:30 [5])	Level 2 Design (RR:0 [1]; TP: 75 [5]; TN:40 [5])
Tv_{BMP} = [(1.0)(Rv)(A)/12] + any remaining volume from upstream BMP(s)	Tv_{BMP} = [(1.5) (Rv) (A) /12] + any remaining volume from upstream BMP(s)
Single Pond Cell (with forebay) **Section 6.5**	Wet ED [2] (24 hr) and/or a Multiple Cell Design [3] **Sections 6.2 and 6.5**
Length/Width ratio OR Flow path = 2:1 or more; Length of shortest flow path / overall length [4] = 0.5 or more **Section 6.3**	Length/Width ratio OR Flow path = 3:1 or more; Length of shortest flow path/overall length[4] = 0.8 or more **Section 6.3**
Standard aquatic benches **Section 6.3**	Wetlands more than 10% of pond area **Section 6.3**
Turf in pond buffers **Section 6.7**	Trees, shrubs, and herbaceous plants in pond buffers; Shoreline landscaping to discourage geese **Section 6.7**
No Internal Pond Mechanisms	Aeration (preferably bubblers that extend to or near the bottom or floating islands **Section 6.8**

[1] Runoff volume reduction can be computed for wet ponds designed for water reuse and upland irrigation.

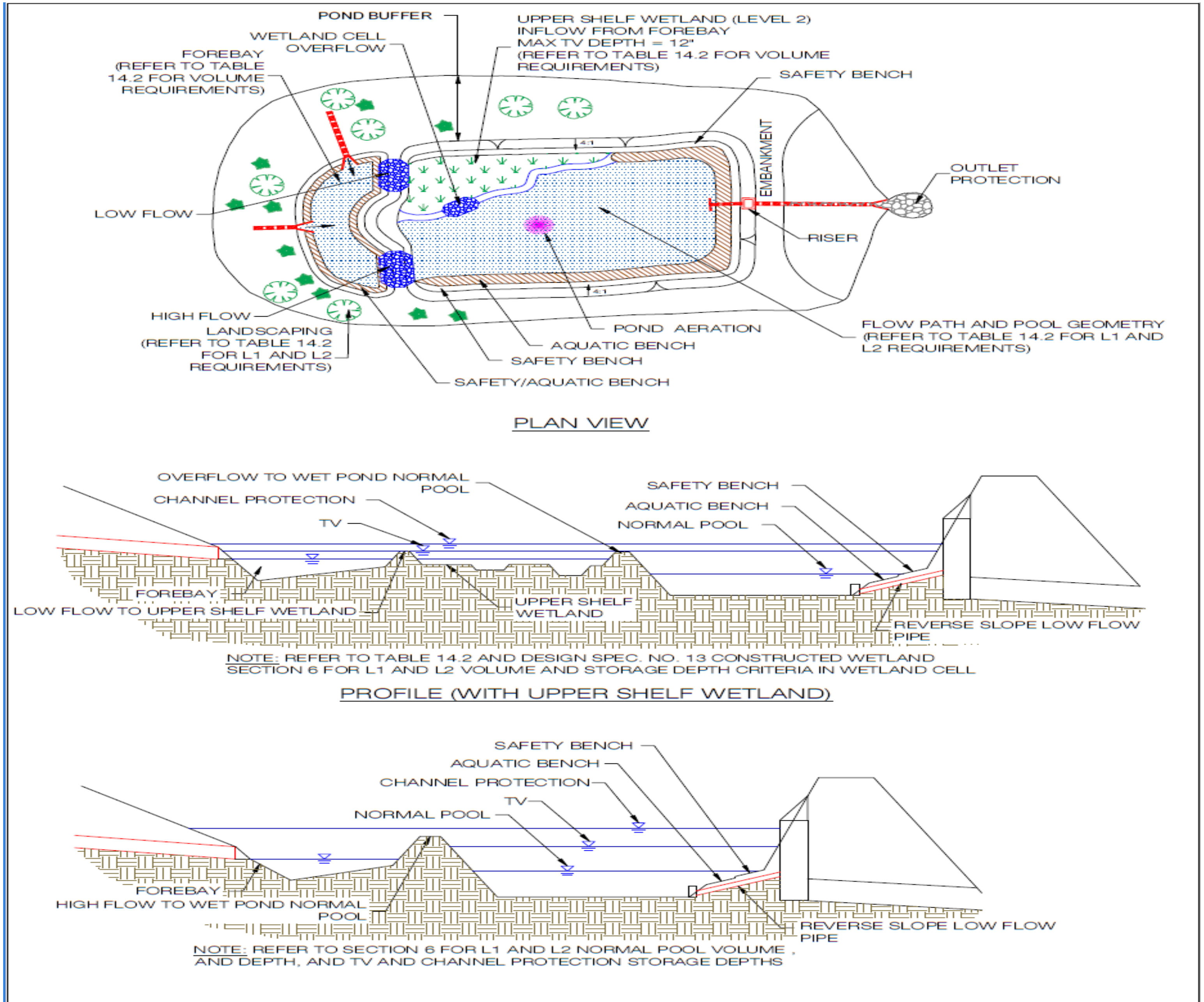
[2] Extended Detention may be provided to meet a maximum of 50% of the Level 2 Treatment Volume; Refer to Design Specification 15 for ED design; **Section 6.2**

[3] At least three internal cells must be included, including the forebay

[4] In the case of multiple inflows, the flow path is measured from the dominant inflows (that comprise 80% or more of the total pond inflow) **Section 6.3**

[5] Due to groundwater influence, slightly lower TP and TN removal rates in coastal plain (**Section 7.2**) and CSN Technical Bulletin No. 2. (2009)

Wet Pond Design Schematics



Extended Detention Ponds

VIRGINIA DEQ STORMWATER DESIGN SPECIFICATION No. 15

VIRGINIA DEPARTMENT OF ENVIRONMENTAL QUALITY

Table 35: Summary of Stormwater Functions Provided by ED Ponds

(From Spec. No. 15, Table 15.1, page 2)

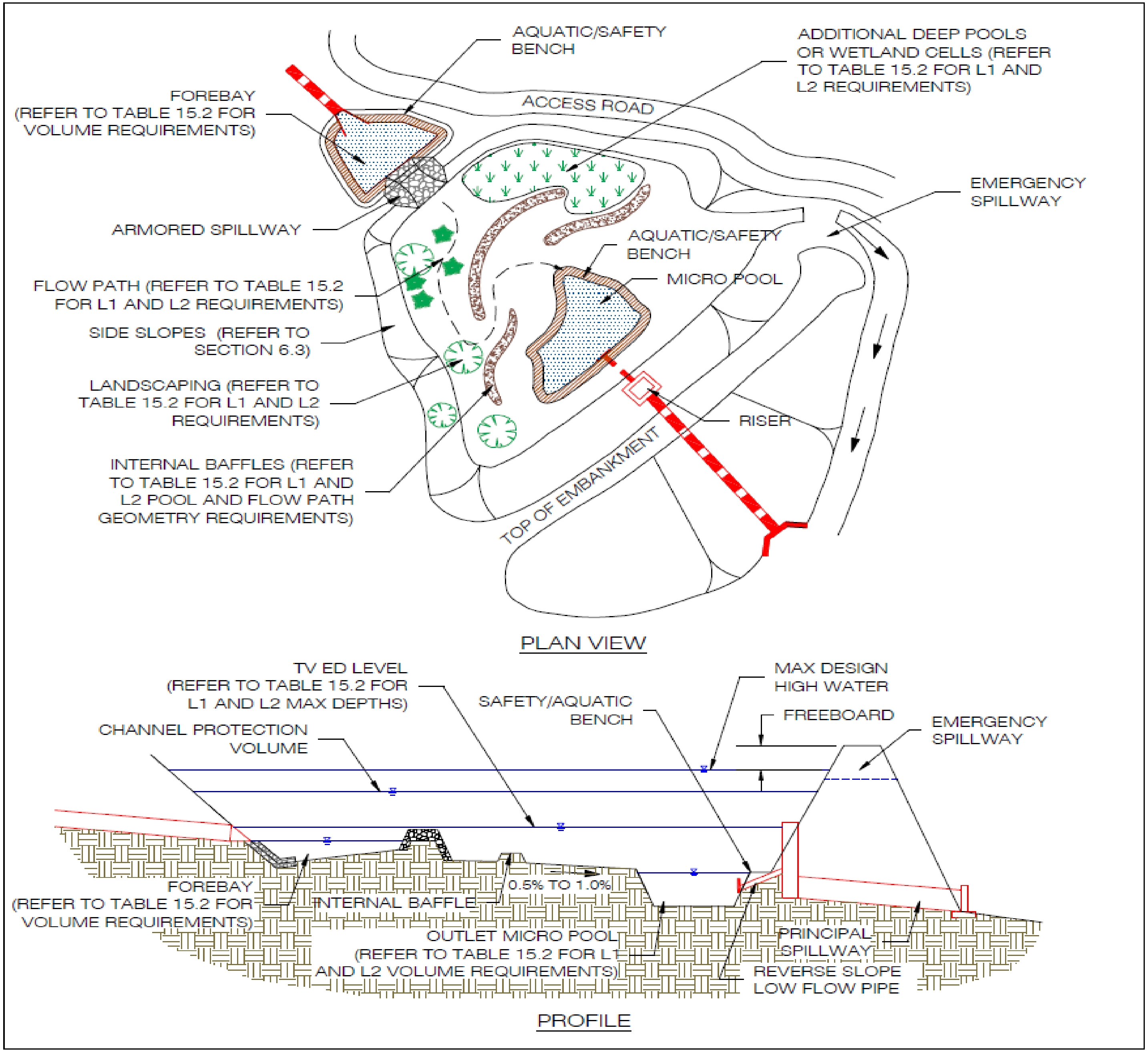
Stormwater Function	Level 1 Design	Level 2 Design
Annual Runoff Volume Reduction (RR)	0%	15%
Total Phosphorus (TP) EMC Reduction[1] by BMP Treatment Process	15%	15%
Total Phosphorus (TP) Mass Load Removal	15%	31%
Total Nitrogen (TN) EMC Reduction[1] by BMP Treatment Process	10%	10%
Total Nitrogen (TN) Mass Load Removal	10%	24%
Channel Protection	Yes; storage volume can be provided to accommodate the full Channel Protection Volume (CP_V)	
Flood Mitigation	Yes; flood control storage can be provided above the maximum extended detention volume	
[1] Change in event mean concentration (EMC) through the practice. The actual nutrient mass load removed is the product of the removal rate and the runoff reduction rate (see Table 1 in the *Introduction to the New Virginia Stormwater Design Specifications*).		

Table 36. ED Pond Design Criteria

(From Spec. No. 15, Table 15.2, page 2)

Level 1 Design (RR:0; TP:15; TN:10)	Level 2 Design (RR:15; TP:15; TN:10)
Tv_{BMP} = [(1.0) (Rv) (A)] / 12 + any remaining volume from upstream BMP(s)	Tv_{BMP} = [(1.25) (R_V) (A)] / 12 + any remaining volume from upstream BMP(s)
A minimum of 15% of the Tv in the permanent pool (forebay, micropool) **Section 6.5**	A minimum of 40% of Tv in the permanent pool (15% in forebays and micropool, and 25% in constructed wetlands) **Sections 6.2 and 6.5**
Length/Width ratio *OR* flow path = 2:1 or more; Length of the shortest flow path / overall length = 0.4 or more. **Section 6.3**	Length/Width ratio *OR* flow path = 3:1 or more; Length of the shortest flow path / overall length = 0.7 or more. **Section 6.3**
Average Tv ED time = 24 hours or less. **Section 6.2**	Average Tv ED time = 36 hours. **Section 6.2**
Vertical Tv ED fluctuation may exceed 4 feet. **Section 6.3**	Maximum vertical Tv ED limit of 4 feet. **Section 6.3**
Turf cover on floor **Section 6.7**	Trees, shrubs, and herbaceous plants in upper elevations, and emergent plants in wet features **Section 6.7**
Forebay and micropool **Section 6.5**	Incudes additional cells or features (deep pools, wetlands, etc.) **Sections 6.2 and 6.5**

Typical Extended Detention Pond Plan and Profile



Questions?

VIRGINIA DEPARTMENT OF ENVIRONMENTAL QUALITY